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STARLAB
UV-OPTICAL TELESCOPE FACILITY
A SUMMARY REPORT
VOLUME 1

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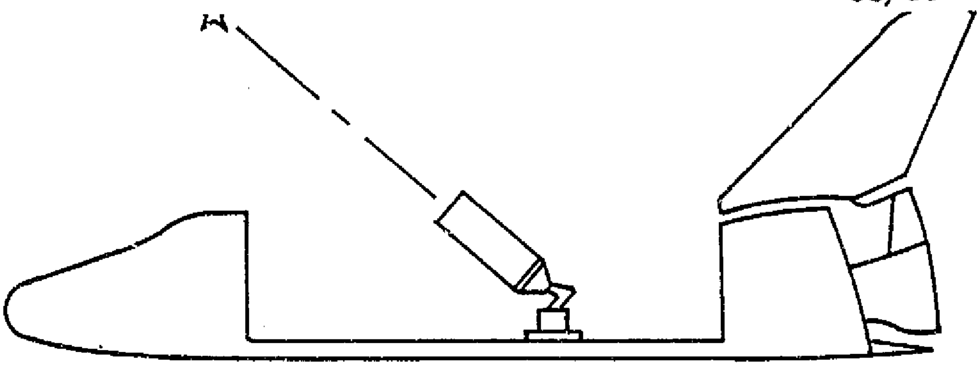

National Aeronautics and Space Administration
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FOREWORD

The advent of the Space Shuttle offers the greatest single leap in our ability to observe the distant universe since the invention of the photographic plate. Astronomy will be progressing into a totally new and unexplored regime well beyond the capabilities of ground-based instrumentation. It will be impossible for any single space telescope to fully exploit this unprecedented opportunity, and astronomers must bring all their experience and wisdom to bear on the establishment of a balanced yet high performance space observatory program. To a large degree, the telescopes of this observatory program will be interdependent, and none could achieve its full potential in the absence of the others. The first generation telescopes of this observatory program include Space Telescope, the Shuttle Infra Red Telescope Facility, a very wide-field UV survey telescope, and the STARLAB facility described in this report.

ACKNOWLEDGEMENTS

The present Facility Definition Team (FDT) selected by NASA Headquarters through AO #3 is responsible for the scienctific rationale and objectives for the STARLAB facility and for the scientific review of the related enginerring design studies.

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SUMMARY

Objectives

To obtain astronomical observations in the visual and ultraviolet portion of the spectrum. Scientific investigations can be conducted in the following high priority categories:

High Angular Resolution Imagery Over Wide Fields

The cosmic distance scale
Evolutionary history of nearby galaxies
Structure and evolution of clusters of galaxies
Deep extragalactic imagery for cosmological tests
Advanced stellar evolution in star clusters
The interstellar medium

Far Ultraviolet Spectroscopy

Deuterium/hydrogen ratio
High-temperature component of the interstellar medium
Molecular hydrogen

Synoptic Planetary Observations

Absorption and emission line imagery
Zonal and meridional motions
Planetary and cometary spectroscopy

Quick Reaction for Special Applications

The facility will provide scientific flexibility by readily accommodating new instruments. The use of photographic film and the rapid reconfiguration is possible because STARLAB is flown in the Shuttle-attached mode.

Instrument

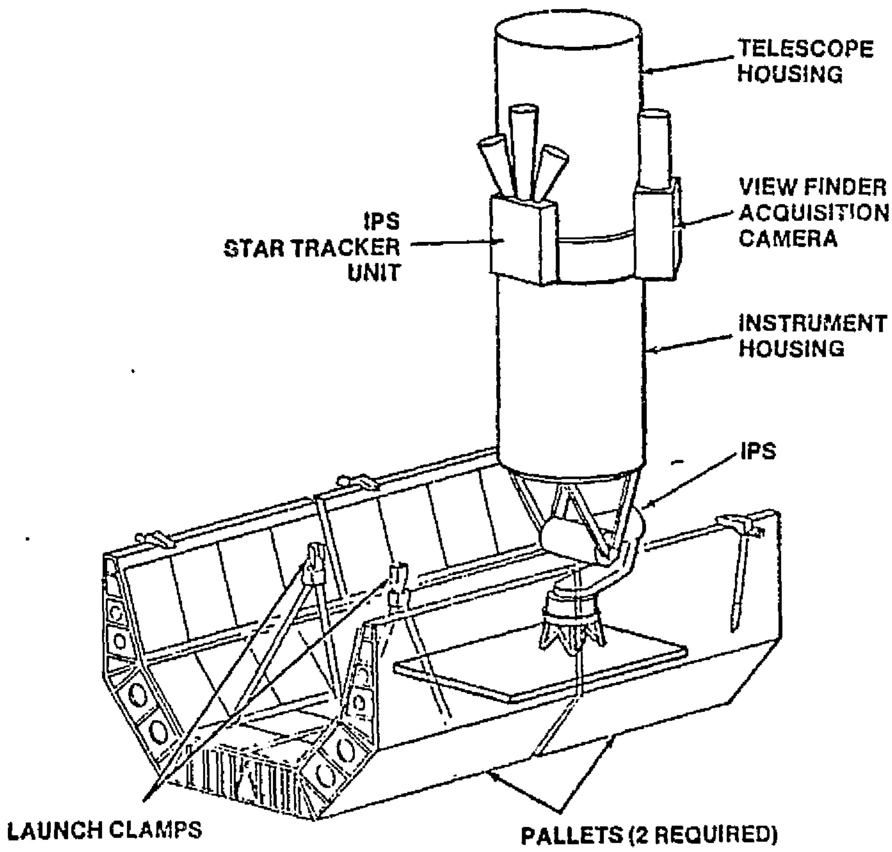
STARLAB is a 1-meter aperture f/15 telescope facility which will accommodate a wide variety of Principal Investigator-furnished focal plane instruments.

Mission Description

A seven to thirty-day duration, orbiting astronomical optical observatory at a nominal 300 km altitude. Inclination angles and launch dates make maximum use of the Earth's shadow. The mission platform is a dedicated, two-pallet payload for a Spacelab/Shuttle sortie. The mission will be organized to fulfill scientific objectives with each mission plan tailored to the complement of scientific instrumentation that Starlab carries.

Status

Mission feasibility is confirmed. Phase A studies are completed, and five Phase B critical subsystem studies have been completed. The study results assure a low-cost facility approach consistent with state of the art technical development. Growth potential is provided in the following areas: guidance, the inclusion of gyros and photon-counting acquisition/tracking devices without structural modifications; detectors, the incorporation of "current" detector matrices and electrographs; optical coatings, the use on dedicated missions of special optical coatings to extend the UV response; scientific instrumentation, the ability to fly innovative focal plane instrumentation.



STARLAB

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I. INTRODUCTION

The STARLAB Program has been in existence for more than four years. The accomplishments to date include both the feasibility definition and detailed design study efforts on critical subsystems. The program has had broad support from both the scientific community and the major hardware design/development contractors. The basic Telescope facility would be obtained through a competitive major procurement process and managed by the Goddard Space Flight Center. The scientific instrumentation, over the projected life span of STARLAB (10 years), would be provided by competitive selection process and obtained through the principal investigators. The capabilities of STARLAB which make it a unique facility are described in Section II. The Scientific Programs are presented in Section III; Section IV is a technical description of the STARLAB Facility.

1.0 STATUS SUMMARY

1.1 PHASE A FEASIBILITY STUDY

Phase A (Task I), which consisted of several Feasibility Studies, is complete. The Feasibility Reports are included in the references.

1.2 PHASE B SUBSYSTEM AND SYSTEMS DESIGN

Phase B (Task II), which consisted of six design assignments extending the concepts presented in Phase A, is described in Section V of this document. In addition a summary of each study is presented in Section VI, Technical

Conclusions. Section VII, Recommendations, is a summary of the recommended further study areas in each subsystem design. The Phase B design tasks completed were:

- Task II A, Optical Design Study
- Task II B, Instrument Design Concept Study
- Task II C, Structural and Thermal Design Study
- Task II D, Acquisition and Tracking Design Study
- Task II E, Electronics/Command and Data Handling Study

The Facility Systems Design Study was to have consolidated all of the previous subsystem studies into one system study and improve system constraints on the subsystem studies. In addition, the following facility wide requirements were to be addressed:

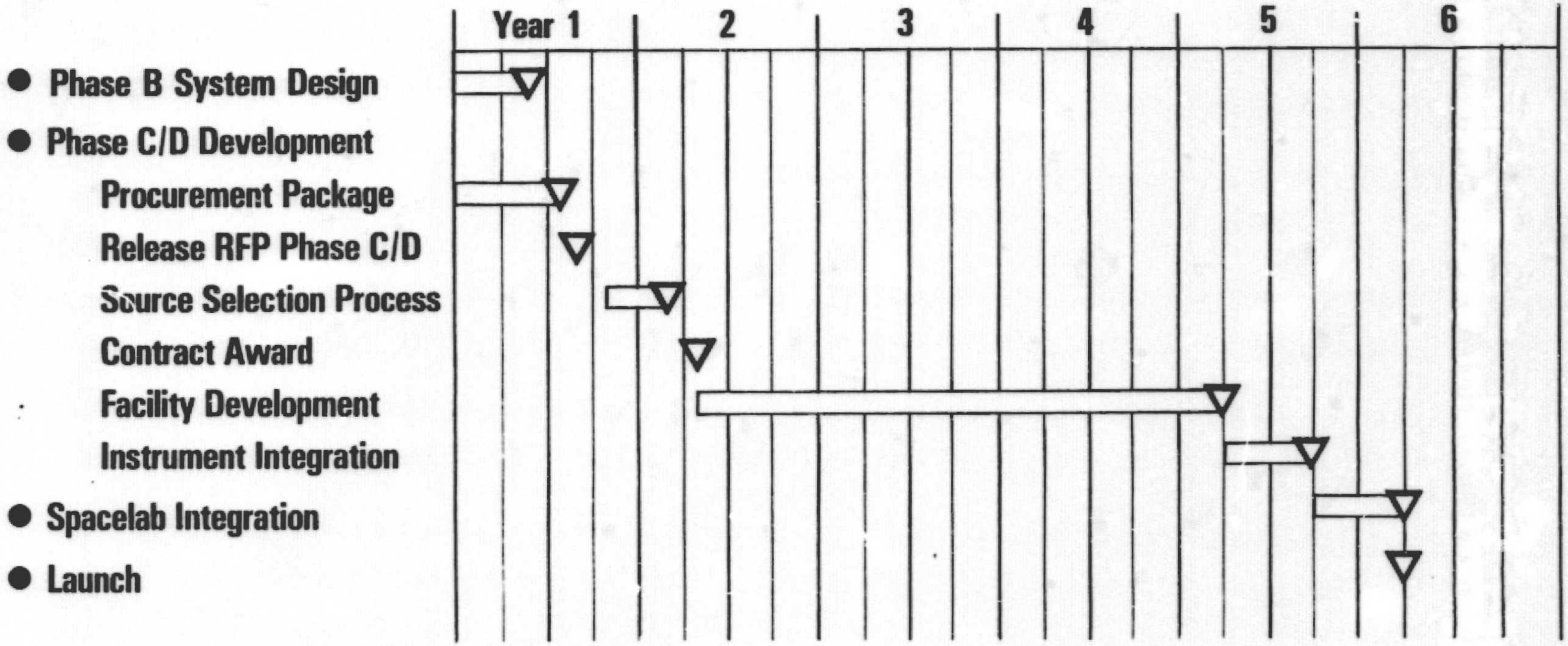
- Contamination Control
- Integration, Ground Support, and Calibration
- Reliability, Quality Assurance, and Safety
- Program Planning (Programmatics)

The Facility Systems design Statement of Work (SOW) is included in Volume II Appendices.

1.3 PHASE C/D DEVELOPMENT

Phase C/D (Task III) involves the procurement activities, STARLAB development, STARLAB/SHUTTLE integration and the launch activities. A schedule is included which projects the first launch based on a new start.

STARLAB Development Schedule



II. CAPABILITIES OF STARLAB

The Space Science Board of the National Academy of Sciences identified a one-meter, diffraction-limited telescope as the "prime complement" to the Space Telescope (ST). In fact, it is clear that a complete space observatory for UV-optical astronomy requires three telescopes: ST, with its maximum field of view of about 3 arc-minutes; STARLAB, with a field area approximately 100 times that of ST; and a wide-field UV survey instrument with a field area 100 times that of STARLAB. The wide field survey telescope would produce data frames with areas and limiting magnitudes comparable to those of ground-based Schmidt telescopes. However, it is STARLAB which bears the same relationship to ST as the 48-inch Palomar Schmidt did to the 200-inch telescope. The remarkably fruitful collaboration between those two instruments gives some indication of the potential scientific return from an ST/STARLAB combination in space.

STARLAB is intended to be a highly versatile, general purpose telescope capable of accommodating a wide variety of Principal Investigator-designed focal plane instruments. As the Feasibility Definition Team (FDT) considered the desirable properties of the telescope, it become obvious that the highest priority need was for high resolution imagery over large fields. With special correctors in place near the focal plane, a large field area can be achieved with conventional telescope designs. The particular design recommended by the FDT represents an effective compromise between large field of view and high resolution and is an appropriate complement to ST's data field. There is little scientific justification for adopting more exotic and costly designs (e.g., all-reflecting systems) which might offer only another factor of 2-3 in field area.

Thus, the high resolution, large area data field became the design driver for STARLAB. However, careful consideration was given to preserving its versatility (e.g., use of multiple instruments on a given flight) and to avoiding constraints in the design which might preclude its use over the next decade for programs presently unforeseen.

STARLAB has unique capabilities which will allow it to make definitive scientific contributions in many areas at the frontiers of astrophysics. In particular, STARLAB has the following capabilities which are not available to ST:

- Using refractive correctors, STARLAB will provide a flat data field $\geq 0.5^{\circ}$ in diameter with image diameters of 0.3 arc-sec (70% encircled energy). This field is 100 times the area of the ST Wide Field Camera. Total spectral range is from 1300-12000 Å. Bandwidths for single exposures range from several 100 Å in the 1300-1800 Å region to 6000 Å longward of 3000 Å. For a given bandwidth, detector and exposure time, STARLAB's limiting magnitude for point sources will be about 1.5 magnitudes brighter than ST's.
- Without refractive correctors, the flat field is 0.1° in diameter or 5 times the ST Wide Field Camera area. This field is available at the axial focal plane (with only two reflections) for far ultraviolet imaging.
- STARLAB can carry optics specially coated for high far-ultraviolet reflectivity. Such coatings will not be used on ST because they are both conditionally stable and require special environmental protection. STARLAB will be the only major instrument since OAO-C to have access to the astrophysically important 950-1150 Å region.
- Immediate (post-flight) recalibration of photometric instruments is possible with STARLAB, yielding the highest possible photometric accuracy.

- STARLAB can employ film as a detector and storage medium. Electrographic cameras using film offer nearly ideal photometric characteristics, including high quantum efficiency, high resolution, large dynamic range, and high photometric precision.
- STARLAB can accomodate complex, evolving, or unproven experimental components, including detectors still under development. Experiment technology is expected to be near state-of-the-art. One of the most important support functions STARLAB can provide ST is to test experimental detectors on orbit.
- STARLAB experiments can employ equipment specifically tailored to individual programs, such as narrow band filters tuned to ammonia absorption bands for planetary imaging or to selected redshifts for particular clusters of galaxies.
- Experiment control from scientist on board the Shuttle is likely to make STARLAB experiments more flexible than those on a free flyer. STARLAB will be the only large space telescope capable of observing Mercury, Venus and other planets near conjunction, or comets near perihelion. For these applications, on-board control is essential to prevent sunlight striking the telescope primary. The Shuttle body itself can be used as a sunshield for such programs.

The effectiveness of STARLAB will be increased by flying more often and by extending the duration of the missions. The facility has been designed for quick turn-around with minimal constraints imposed on PI experiments, and it is reasonable to expect two flights per year (averaged) for a total of 4-6 weeks of on-orbit operations per year. STARLAB operations should be very efficient, with capability for either automatic control, direct ground control, or control by on-board scientists.

Four major instruments in addition to a high resolution, small field camera (the "planetary" camera) can be carried on each flight, insuring that both the daylight and dark portions of each orbit can be used to maximum advantage and that useful data are returned even if some experiments fail. Owing to the large FOV and the fact that wide field imagery will likely be the highest priority objective of most missions, STARLAB can return imagery data in a number of important applications at a much higher rate (averaged over a year's operations) than ST.

To further increase the utilization of STARLAB the FDT recommends that careful consideration be given to making the facility capable of both sortie-mode and short-term free-flyer operation. Its scientific potential would be enhanced enormously if it could be placed into near-Earth orbit and serviced perhaps every six months. Most of the advantages of sortie-mode operation, as previously described, would not be compromised in this situation--including the possibility of using film. There are several low-cost alternatives under consideration by NASA whereby the short-term free-flyer configuration could be implemented. The FDT note that STARLAB is one of the few Shuttle-based facilities which is readily adaptable to free-flying.

III. SCIENTIFIC PROGRAMS

The Space Telescope represents an enormous leap in observational capability over current ground-based instrumentation--perhaps a factor of 100 in limiting detectability. If the pattern common to existing telescopes is followed, there will be great pressure to operate ST near its limits, implying relatively little observing time for brighter targets. Furthermore, ST is constrained by design in a number of ways. One example, of course, is its very small field of view for direct imaging. Another is the relatively small complement of filters ST can carry. A number of sets of narrow band filters centered on various ultraviolet and optical emission lines with each set tuned for a particular redshift would be of enormous value in many extragalactic problems, but only a few such sets can be accomodated. A final example is that ST will not have useful response in the far UV ($\lambda < 1100$ Å).

Clearly, then, there are many exciting scientific problems beyond the capability of ground-based telescopes but which ST will also not be able to address effectively. It is in these areas where STARLAB will make definitive contributions.

In addition, STARLAB will be a powerful support instrument for ST, insuring that ST's observing time--the most valuable in astronomical history--is used in the most effective possible manner. (Markarian galaxies are good examples of objects of great astrophysical interest which could not have been studied using only the 200-inch telescope and where a collaboration with a large field instrument was essential. Undoubtedly, many more such classes of objects will emerge between the effective ground-based visual limit of 23-24 mag and that of ST at 28-29 mag.) It is obvious that STARLAB would be most effective in its support role if it were operational prior to ST launch.

This report does not consider the ST support functions in detail here, but rather concentrates on three scientific areas where STARLAB will have major impact in its own right. The broader spectrum of applications for which STARLAB will be suitable is also considered.

It is the opinion of the FDT that STARLAB, because of its high performance design and versatility, will become the most heavily subscribed of the astronomy space facilities and will figure in the research programs of a broader cross section of the astronomical community than reached by any other planned experiment.

A. HIGH ANGULAR RESOLUTION IMAGERY OVER WIDE FIELDS

STARLAB's greatest impact will be on problems requiring high resolution imagery over fields significantly larger than the 2.7 arcmin field of the ST Wide Field Camera. A great many important astrophysical problems fall in this category, ranging from advanced stages of stellar evolution in globular clusters (10-60 arcmin diameter), to the history of star formation in nearby galaxies (12° for the Large Magellanic Cloud, 10 arcmin for Virgo galaxies), to studies of clusters of galaxies (17 arcmin at $z = 0.3$). In these areas, STARLAB can be expected to provide a rich scientific return not obtainable from any other space facility.

A number of programs suitable for STARLAB imagery are discussed below, For point sources, STARLAB's limiting magnitude will be about 1.5 magnitudes brighter than that of ST for a given detector and integration time. In a 30-minute exposure, while in the Earth's shadow, STARLAB will reach $V = 25$ with $S/N = 5$ using a 1000 Å bandwidth and a system with an overall detection efficiency of 0.1. With a 6000 Å bandwidth, the limiting magnitude is $V = 26$.

In almost all of the problems described below, STARLAB will give performance distinctly better than that of any ground-based telescope by virtue of its excellent image quality, darker sky background (by one magnitude in the visible but by 4 magnitudes in the near infrared), access to the ultraviolet, and capability for extremely broad-band exposures. However, in those many problem areas requiring high precision photometry of point sources in crowded fields or superposed on a bright background, STARLAB will have an insuperable advantage over ground-based instrumentation because its resolution will be ten times better than that typically set by seeing in the atmosphere.

STARLAB's large field of view also allows a much faster data return in many situations than ST can provide--especially for programs requiring large statistical samples, selection of the very best targets (unblended, free of reddening, etc.) for precise photometry, study of positional dependences, and searches for rare types of objects. For example, STARLAB could photograph approximately ten times as many Cepheid stars in M31 to a given photometric precision within a given observation time as could ST.

One powerful auxillary device which STARLAB could use to advantage in many imaging applications is a grating + prism ("grism") combination ahead of the focal plane. Such a device would yield, with spectral resolution ~ 100, information over the entire high resolution field. On ground-based telescopes, grisms have proven to be very effective in discovering faint emission line objects sich as QSO's at large redshifts. Used on STARLAB, the detection threshold will be several magnitudes fainter, the spectral resolution several times higher and access to the ultraviolet will greatly extend the range of redshifts which can be explored with this technique. In globular clusters, deep extra galactic fields, and nearby galaxies a single grism exposure can yield rough ultraviolet energy distributions for thousands of objects at once.

1. <u>The Cosmic Distance Scale</u>

Direct determination of distances to many galaxies within 150 Mpc in order to better understand cosmic expansion is one of the principle reasons for sending large telescopes into space. It is intended that ST will provide data on crucial links in the distance scale such as RR Lyrae stars in M31, Cepheids in the Virgo cloud, HII regions in distant spirals, and globular clusters in Coma. However, 50 years of ground-based experience have made it clear that accurate extragalactic distance determinations are extraordinarily different to secure. The recently recognized fact that there are metallicity differences between galaxies and metallicity gradients within galaxies implies significant cosmic dispersion in the properties of any distance indicator. <u>It is essential that a large statistical sample of each distance indicator be obtained</u>.

STARLAB's large data field is particularly well sutied to this task. The most important indicators and the respective distances to which they could be studied by STARLAB are: RR Lyrae (500 kpc);Cepheids, brightest Pop II stars and main sequence OB stars (3 Mpc--the M81 group); novae (20 Mpc--the Virgo cloud); brightest supergiants in spiral and irregular galaxies (80 Mpc); sizes of HII regions (70 Mpc for 3 pixel coverage); and globular clusters (100 Mpc). Three major clusters (Virgo, Pegasus and Perseus) lie within the 100 Mpc limit.

2. <u>Evolutionary History of Nearby Galaxies</u>

In addition to the distance criteria cited above, an unprecedented amount of information on individual stars in nearby galaxies, and hence on their evolutionary history, will be available to STARLAB. Systems nearer than 100 Kpc, such as the Magellanic Clouds and the Sculptor dwarf system, can be sampled to $M_V \sim +6$, well below the main sequence turnoff. The horizontal branch can be studied in all metal-poor dwarf systems in the local group. The distribution of metal content and positional variation of star formation may be studied in detail via individual variable stars and the morphology of field and cluster HR diagrams. For this program, ultraviolet energy distributions will be extremely valuable as sensitive indices of temperature for hot stars and of metallicity. Of special interest are star formation rates in the vicinity of spiral shocks derived from observations of hot main sequence stars in galaxies up to 4 Mpc distant. Galaxies up to 50 Mpc distant are significantly larger than the ST field of view, while only the Magellanic Clouds and M31 are larger than the STARLAB data field. See figure 3-1.

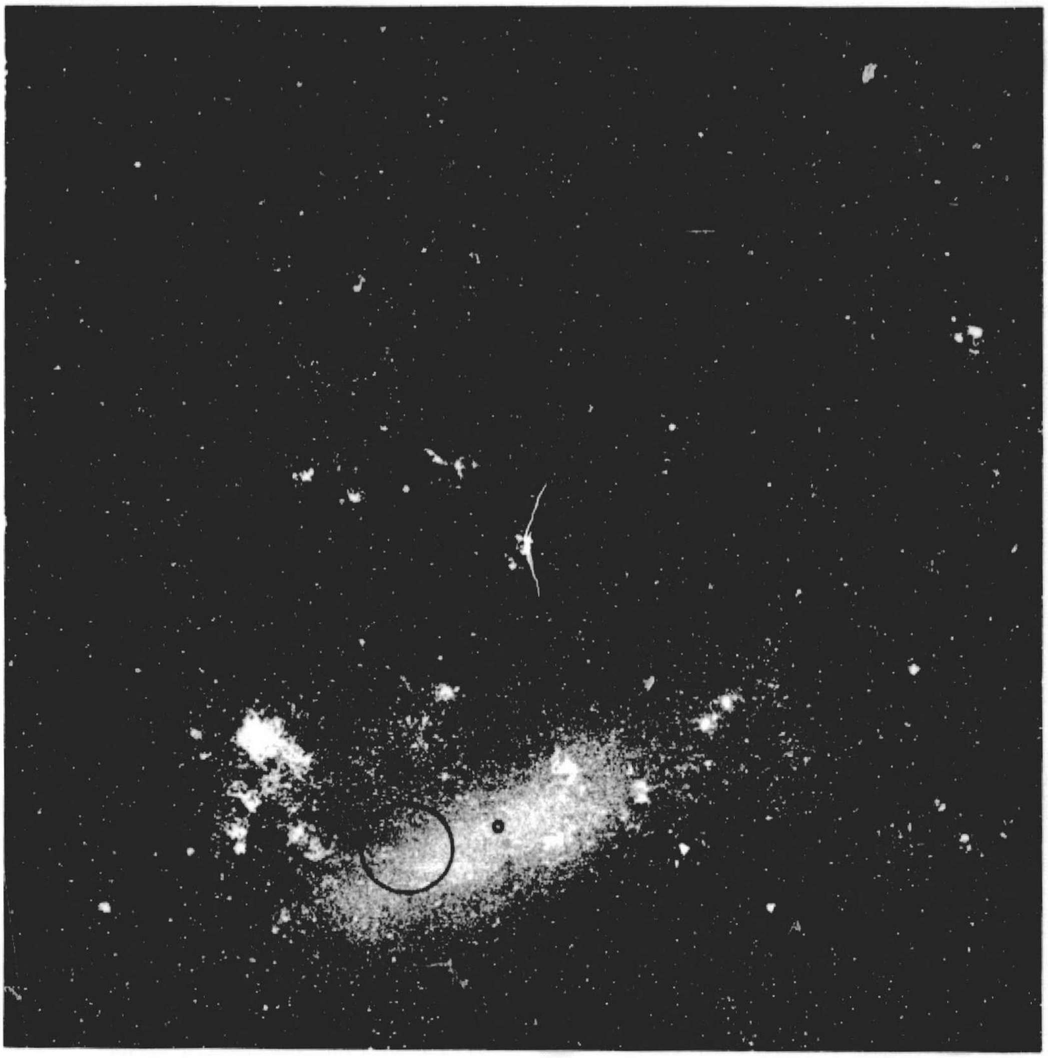


FIGURE 3-1. STARLAB AND SPACE TELESCOPE (ST) FIELDS OF VIEW PROJECTED ON THE LARGE MAGELLANIC CLOUD

The wide-angle photograph ($6^{o} \times 6^{o}$) shows the entire galaxy and illustrates the dense star clusters and star clouds which require the high resolution provided by STARLAB if their stellar make-up is to be studied in detail.

The large circle illustrates the area covered by the STARLAB field. The small circle illustrates the area covered by ST field.

3. Ultraviolet Surface Photometry of Galaxies

Ultraviolet surface photometry of galaxies too distant for many individual stars to be resolved is both of great intrinsic interest and also fundamental for the interpretation of galaxy surface brightness profiles determined for high redshift objects by ST.

a) Continuum UV photometry provides information on the chemical content and age distribution of stars in galaxies. It will give important clues to the history of metal enrichment, the extent of recent star formation in spheroidal systems, and the correlation between star formation and spiral structure in disk galaxies.

b) Studies with narrow band filters centered on such features as O VI 1031 Å, Lyα, C III 1909 Å, Mg II 2800 Å, and the extinction maximum near 2200 Å would yield important information on the distribution and properties of HII regions, supernova remnants, and dust in galaxies.

4. Clusters of Galaxies

For a large cluster, the Abell diameter, which contains ~80% of the cluster's mass, is 6 Mpc. The Abell diameter is smaller than the STARLAB FOV at z ~ 0.2. AT z ~ 1-2 the Abell diameter is still ~ 10 arcminutes.

a) Nearby clusters (z < 0.5)

i) Supernovae are important both astrophysically and also as distance indicators at very high redshifts. STARLAB will have a great advantage over ground based instrumentation in supernovae searches because it will be less confusion-limited by bright galaxy backgrounds and because supernovae are bright in the ultraviolet. A survey of 20 rich clusters should yield about one supernova per week.

ii) It will be important to obtain ultraviolet surface photometry of large samples of galaxies in clusters in order to extend ground based work, already underway, on the nature of galaxy formation.

iii) In the nearer clusters, STARLAB will be able to search for extremely faint galaxies in order to examine the faint end of the galaxian luminosity function. Here it is anticipated that resolution of associations or other concentrations of stars, which is impossible from the ground, will be an important factor in making new detections.

iv) Deep exposures in the ultraviolet (e.g., for redshifted Lyα) and the near infrared with STARLAB will be useful in studying intergalactic material in nearby cluster cores.

b) Distant clusters ($z > 0.5$)

i) At $\underline{z} \sim 1$-2, lookback times are great enough that significant dynamical evolution of clusters may still be occurring. Analysis of the structure of clusters is therefore of great interest. Since a count of background galaxies to several Abell diameters (i.e., 20-30 arcmin) is required, a large FOV such as will be supplied by STARLAB, is necessary.

ii) STARLAB will provide enough spatial resolution to classify galaxies in clusters as $z \sim 1$, thus helping to interpret the unexpectedly large number of blue galaxies now being found at large look back times.

iii) Superclusters have diameters of $\sim$ 30 Mpc or 45 arcmin at $z \sim 2$. Only STARLAB has the capability to study the organization of matter on such scales at high redshift.

5. Deep Extragalactic Surveys

a) At $z \sim 1\text{-}2$, one to two rich clusters are expected per STARLAB FOV. A relatively short program (10 hours' exposure) will therefore provide a large sample of distant clusters for more careful study by STARLAB and ST.

b) Interest has recently been revived in the galaxy count-brightness relation as a world-model/galaxy evolution test, especially since wide field exposures can yield rough redshift information through use of grisms or intermediate-band filters. The test depends on obtaining faint imagery of a very large statistical sample. A single STARLAB field should contain several thousand galaxies to V=24.

c) A single STARLAB frame should contain over a hundred QSO's fainter than V=22. Discrimination from foreground stars is possible with grisms.

6. Stellar Surveys of Our Galaxy

STARLAB can make definitive studies of the stellar population in the nuclear bulge of our galaxy (viewed through gaps in the absorption such as Baade's window) and at the galactic poles. At the poles solar type stars can be detected to distances of 100 kpc. Color statistics will be useful to the limiting magnitude obtainable with long exposures ($V \sim 26$) in determining the structure of the galactic halo. Grisms will provide wide-band spectral energy distributions for a large sample of brighter objects.

7. Stellar Evolution in Star Clusters

Ultraviolet searches for rapidly evolving post-giant stars and white dwarfs in a large sample of galactic and globular clusters will be of fundamental importance in understanding advanced stellar evolution. With STARLAB's superior spatial resolution, large sample color-magnitude diagrams can be obtained for all but the innermost parts of globular clusters, and the positional dependence of their stellar populations can be studied. Many globulars can be sampled to $M_V \geq 10$.

8. The Interstellar Medium

STARLAB's high spatial resolution, wide field, and access to the ultraviolet are powerful tools for the study of interstellar gas and dust in our galaxy. Studies of condensations and filaments in H II regions, planetary nebulae and supernovae remnants and of fine structure in dust clouds (globules, elephant trunks, etc.) will be of great interest. There will be many applications for ultraviolet imaging through narrow band filters centered on selected emission lines or the 2200 Å extinction feature and for ultraviolet polarimetry.

9. Serendipity

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STARLAB is configured such that wide field imagery in a restricted field can proceed while axial instruments are operating. In a year's worth of STARLAB missions, some 40 square degrees of the sky can be surveyed to V ~25 (for point sources) if such exposures are made at every opportunity. Such a survey will constitute an important resource for the progress of astrophysics into areas presently unforeseen.

B. SPECTROSCOPY FROM 900-1200 Å

Of the major facilities planned or in orbit to observe far ultraviolet spectra (Copernicus, IUE and ST), only Copernicus can record efficiently below 1100 Å since it has optical surfaces with LiF overcoatings and no transmission elements for the beam to penetrate. The wavelength range extending from the Lyman Limit to the 1100 Å cutoff for normal UV coatings is a particularly valuable region for astronomical research, especially for studying the composition and physical state of gases in the interstellar medium.

The UV spectrometer in STARLAB with a resolution $\sim 10^4$ will not only allow us to observe intrinsically fainter and more distant objects than those recorded by Copernicus, but also will enable us to acquire the information at a much greater rate (see the caption for Figure 3-2). Summarized below are a few scientific problems which were addressed by observations from Copernicus, bu which could only be investigated at wavelengths below 1100 Å.

1. Atomic Deuterium

The Lyman-α (and frequently Lyman-β) interstellar hydrogen lines will swamp the accompanying deuterium lines in all but the closest stars. Hence, the higher members of the Lyman series (at 972 Å, 950 Å, 938 Å, etc.) must be observed. The ratio of deuterium to hydrogen in the interstellar gas, which reflects upon a universal deuterium abundance, is especially relevant to our estimating the present average density of the universe, if one makes use of the theories of nucleogenesis in the early stages of the primordial explosion. Although there are many other astronomical situations where abundances of deuterium atoms may be sensed, determinations of interstellar atomic D/H ratios provide what is probably the most straightforward measure of the universal ratio.

In establishing whether the interstellar ratio is not significantly altered from the primordial value, it would be useful to reach beyond the initial Copernicus results and detect gas at high galactic latitudes which may be somewhat isolated from the material processed through stars (and supernovae) in the disc of the galaxy. Another approach, suggested by Ostriker and Tinsley, would be to examine the relationship of the deuterium abundance to variations in metalicity in different parts of our galaxy. A marked anti-correlation of the two would indicate that the primordial deuterium abundance has been significantly reduced as material cycles through stars, while a positive correlation would indicate that some process connected with stellar activity produces deuterium, and at a rate which outstrips the destruction rate.

2. O VI (1032 Å, 1038 Å)

Observations of weak and broad absorption features due to interstellar O VI have established the existence of a tenuous, high-temperature

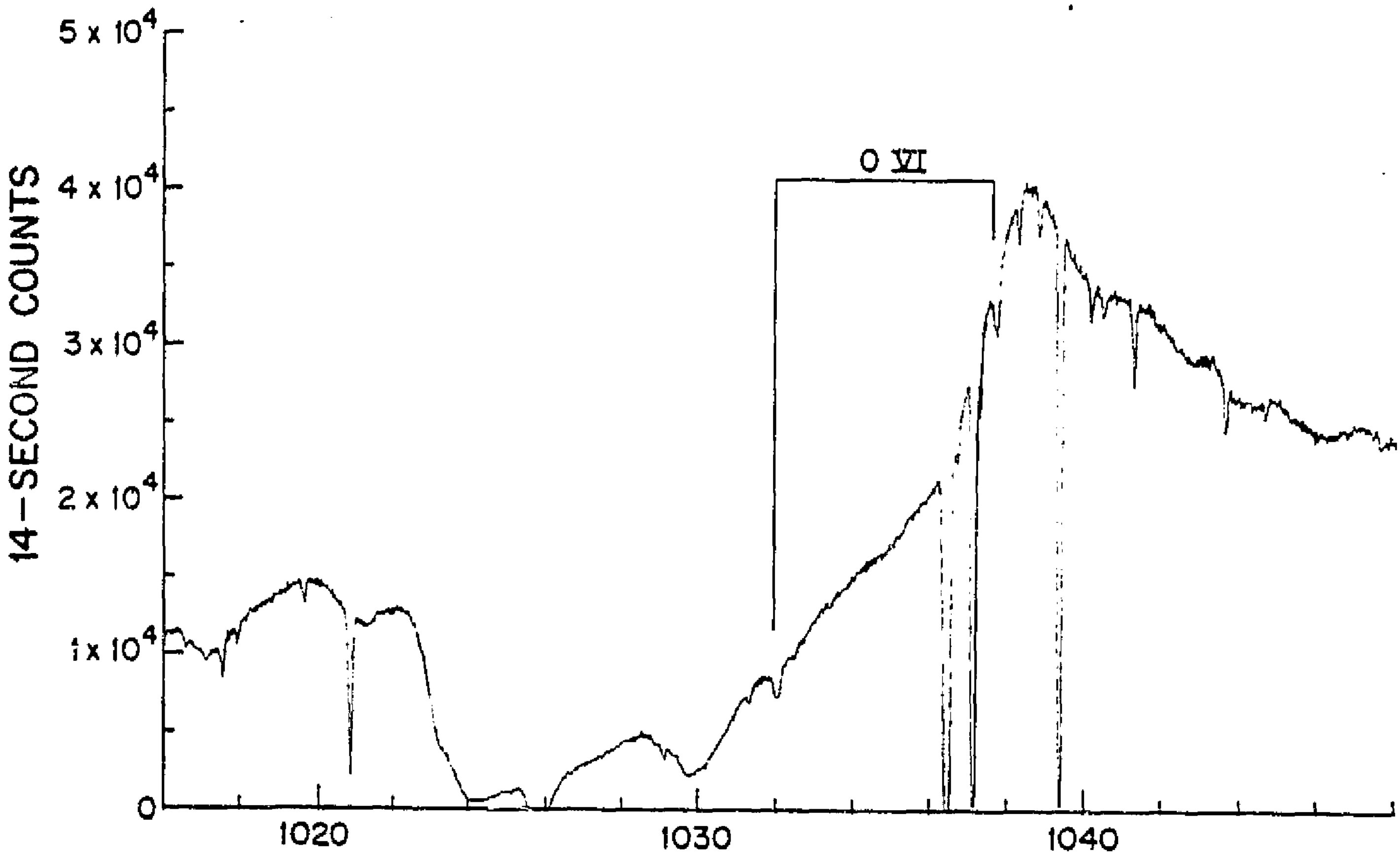

FIGURE 3-2. COPERNICUS SPECTRUM SCAN OF ζ PUPPIS

Copernicus spectrum scan of the O5f star ζ Puppis between 1016 and 1048Å. Superposed on the star's broad P-Cygni profile from the O VI resonance lines are sharp interstellar absorptions from Si II (1020.7Å), O VI (1031.9, 1037.6Å), C II (1036.3, 1037.0Å), O I (1039.2Å) and a number of weak absorptions by H_2 in excited rotational levels. The observation shown on this tracing took 21 1/2 hours of Copernicus Telescope time to complete; the spectrograph on STARLAB could record a complete spectrum of this star from 900 to 1200Å in a single orbit with somewhat better resolution and signal-to-noise ratio.

component of the interstellar medium. Absorptions by other highly ionized species, such as S IV, N V and Si IV, do not seem to appear, and this is probably a consequence of the gas being at a temperature in excess of a few times 10^5 ^{o}K. Hence, experience up to now suggests O VI may be the only conspicuous tracer. This is an especially important consideration for research by satellites more sensitive than Copernicus, since we could expect to register spectra stars very distant from the plane of the galaxy and probe the conditions in the galactic halo regions. Out present knowledge of the density, composition, temperature and dynamics of high-temperature gas in the halo is indeed sparse, and additional information here would be valuable in our understanding of galactic structure and evolution.

An insight on the distribution of galactic material at large distances is also relevant to a possible explanation for intermediate redshift lines (from intervening galaxies) appearing in QSO spectra. Finding very many suitable targets (O and B type stars) far from the galactic plane is not an easy task, since the scale height of young stars, by necessity, is not much different than that of the dense interstellar matter out of which they formed. On the other hand, the sensitivity of the STARLAB spectrometer is sufficient to record the Far UV spectra of the most luminous early-type stars in the Magellanic Clouds. In addition to giving us a long path through the halo of our own galaxy, these stars themselves are embedded in material with a markedly different evolutionary history.

3. <u>Molecular Hydrogen Lyman (and Werner) Band Systems</u>

The importance of molecular hydrogen is almost self-evident, in view of its high abundance in dense accumulations of gas and the unexpectedly high degree of rotational excitation which has been found. Relative populations in various stages of rotational excitation may be observed. The longest wavelength for transition from the lowest rotation and vibration level in the Lyman system is 1108 Å. Also, absorptions from HD are easily detected; principal lines of the Lyman system start at 1106 Å and go shortward. When compared with the amount of H_2 present and evaluations for the interstellar D/H ratio, measurements of HD give us insight on the rates of ion-molecule exchange reactions in clouds, which in turn are governed by the atomic hydrogen ionization rates.

4. N II and C III (1084 Å, 977 Å)

Neutral nitrogen atoms have an ionization potential just slightly greater than that of hydrogen. Hence, except for ionization by cosmic rays and X-rays, there should be virtually no production on N II in H I regions. Practically all of the observed N II must arise from H II regions, and this ion serves as an ideal probe, not only for the extent of the ionized zones, but also for the representative electron densities, since absorptions from excited fine-structure levels may be observed. Another near coincidence of ionization potentials may be found for neutral helium and singly ionized carbon. It follows that C III should be a good indicator for the amount of helium ionization around the stars. Observations of C III by the Copernicus instrument have been somewhat hampered by the relatively low signal and high background levels near 977 A.

5. Weak Lines Below 1100 Å

Additional benefits for analyzing the interstellar material may result from observations below 1100 Å. There are several weak transitions, from such abundant species as Si II (1021 Å, N I (964 Å), and OI (989 Å), which allow us to circumvent difficulties in the interpretation of stronger lines (at longer wavelengths) which are strongly saturated, even for nearby stars. In addition much can be learned about the structure and composition of stellar atmospheres by analyzing absorption lines below 1150 Å. The peak of the black-body curve occurs near or below 1100 Å for the very hot stars, and a study of the spectral behavior near this maximum is crucial, since it is here that the effects of line blanketing are more important in altering the emergent flux. Also, weak lines show greatest contrast over wavelengths on or below the Planck maximum, since relatively large changes in flux occur for the small temperature differences between the atmospheric levels responsible for the line cores and the adjacent continuum.

In the far ultraviolet there is a wealth of strong resonance lines m highly ionized atoms. The discovery of mass loss from the very luminous early-type stars, using rather primitive rocket-borne spectrographs, exemplifies well the new insights which may result from examining short wavelengths. Using a space observatory, scientists would like to continue studies of P-Cygni type profiles from such ions as C III (977 Å), N III (990 Å), O VI (1032, 1038 Å), P V (1118, 1122 Å), S IV (1062 Å) and S VI (944 Å).

C. SOLAR SYSTEM STUDIES

High resolution and accessibility to the IR and UV regions of the spectrum, and the ability to observe at small solar elongation angles will make STARLAB a valuable tool for the study of solar system objects, including planets, satellites and comets. The ability to monitor transient phenomena almost continuously over periods of 1 to 4 weeks gives STARLAB another important advantage over ground-based telescopes.

Even though ST may also be used to observe solar systems objects and will have the advantage of higher resolution and greater aperture, it is likely that specialized equipment, such as imaging spectrographs, polarimeters and medium-and narrow-band filters (tuned, for example, to isolate methane and ammonia absorption bands, sodium D lines or spectral absorption features of minerals), and solid-state imaging arrays for the near-IR (1-5μ) region will not be available on ST. Likewise, the presence of men with STARLAB makes possible delicate and rapid maneuvering of both Shuttle and STARLAB, which will permit observation of planets and comets at much smaller elongation angles than ST can tolerate. For example, it is expected that Mercury at elongation may be observed during the 5-minute period between its rise and the rise of the Sun, and that STARLAB may then be repointed before any significant thermal stress occurs in the telescope optical sytem. The presence of man also makes possible quicker detection and better tracking of transient phenomena.

It has been recommended that a very high resolution planetary camera be carried on every STARLAB flight in order that synoptic photography may be carried out as often as possible. Since exposures on planets will be short, it is expected that relatively little observing time will be required to accumulate significant amounts of synoptic data on all the planets. It is expected that this camera will use all-reflecting transfer optics to maintain broad spectral response, and will be designed to ensure that resolution will be telescope optics limited and not detector limited. The resulting 0.1 arcsecond resolution at 4000 Å translates to a linear resolution of 75 kilometers at a distance of 1 AU. By use of image processing, it is possible to make further imporvement in resolution at some expense to photometric fidelity.

Although high resolution direct imaging would be a primary solar system observing program, extremely valuable spectrophotometric data could also be obtained by use of the spectrographs and spectrophototmeters which are also expected to be available with STARLAB.

The following sections indicate some scientific problems regarding solar system objects on which STARLAB data would have a significant bearing.

1. Direct Imaging Programs

Venus. Resolution: 50 to 100 km. Observations of the 100 m/s UV clouds would lead to a better understanding of zonal and meridional motions than has been acquired so far through Mariner 10 and ground-based imaging. Although Mariner 10 photography has been very valuable in providing clues to the plant's atmospheric circulation, the interval of observation was less than 10 days and, therefore, represents only a momentary look at an atmosphere which ground-based photography suggests is constantly changing.

Spectrophototmetry and polarimetry at high angular resolution from the visible to vacuum ultraviolet regions of the spectrum should lead to positive identification of the composition and size distribution of cloud particles, and bring out any differences between the bright and dark ultraviolet clouds.

The recent identification of bright cloud particles as uniform droplets of concentrated H_2SO_4 is not completely consistent with the observations. Vacuum UV imaging and spectrography in atomic and molecular resonance features would be of great value in understanding the composition and physical processes in the upper atmosphere and ionosphere of Venus.

Mars. Resolution: 30 to 150 km. Narrow-band filters would permit the monitoring of the time-dependent, spatial distribution of minor atmospheric constituents such as CO and O_3, important to studies of Martian aeronomy. The application of far UV imaging and spectrography mentioned for Venus also apply to Mars.

High-resolution STARLAB imagery of Mars would also be valuable for studies of the initial stages of dust storms, and for determining shether the white clouds associated with Martian volcanoes are due to orographic uplift or to local source degassing.

Jupiter. Resolution: 300 to 450 km. STARLAB imaging with resolution comparable to or better than the best obtained by Pioneers 10 and 11 can be achieved (see Figure 3-3). The Voyager missions will obtain photographs with resolution better than 300 kilometers for only 25 days out of a scheduled observing interval of 80 days. The planned Jupiter Orbiter (Galileo) mission will provide more continuous coverage, but will not arrive at the planet until 1985.

Synoptic imaging at regular intervals over a 10-day time base can obtain the zonal and meridional components of the Jovian wind field with mean velocity errors of less than 0.2 m/s. Observations of the Jovian wind field at the visible cloud surface, when combined with high resolution cloud morphology, could lead to a better understanding of the planet's general

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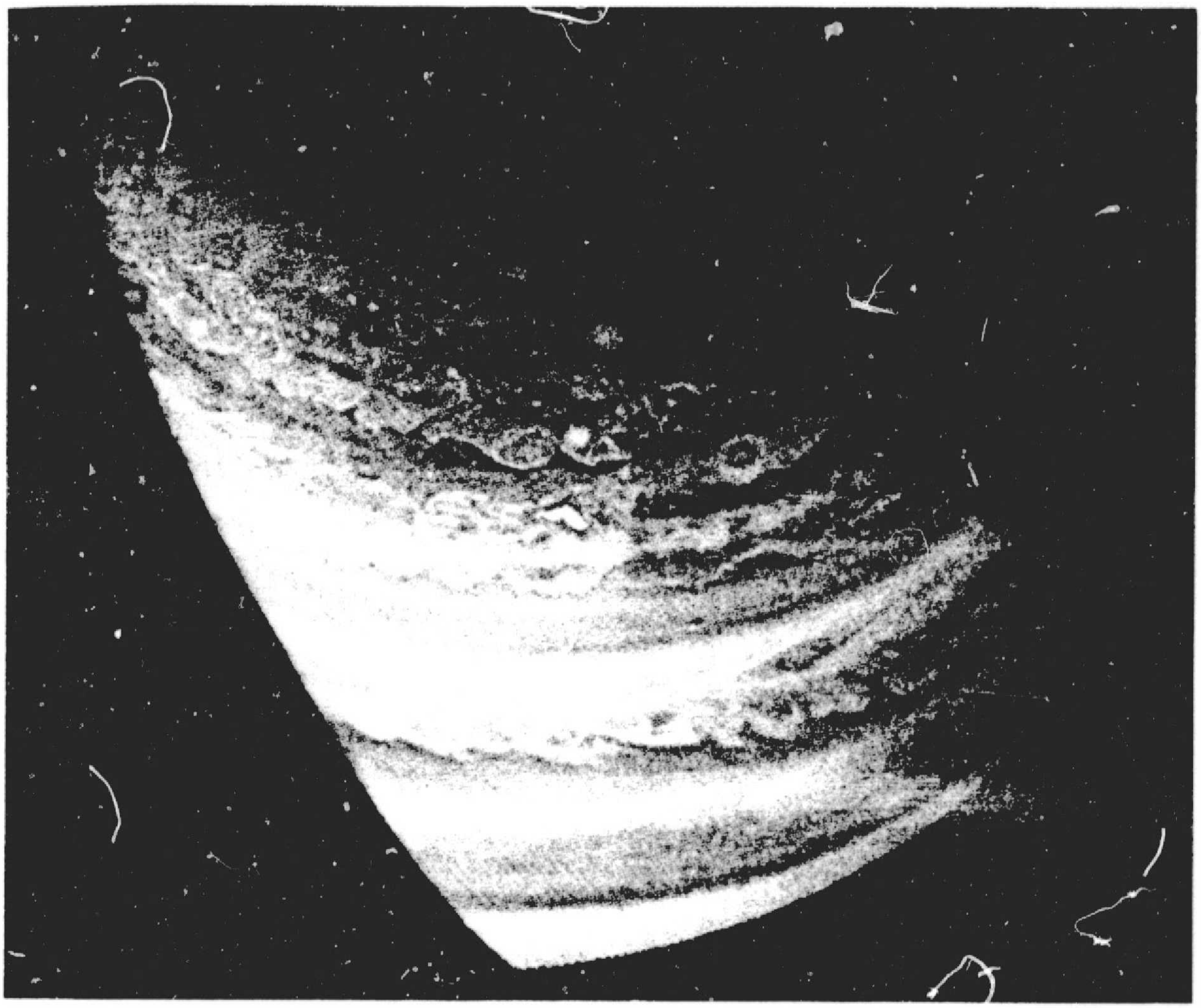

FIGURE 3-3. HIGH RESOLUTION IMAGE OF JUPITER

Pioneer 11 high resolution image of Jupiter in blue light, as observed at a distance of 609,000 km on 3 December 1974. The limiting linear resolution in this view is somewhat greater than 300 km. The excellent image quality provided by STARLAB will allow spatial resolution on Jupiter from earth orbit equaling or exceeding that achieved by Pioneer 10 and 11. The flexibility of SPACELAB operations will allow the use of instrumentation designed for specific research goals - e.g., narrow band interference filters to isolate and map specific spectral features.

circulation. STARLAB can provide even better information on the motions and morphology of small scale cloud features. Like the Earth, Jupiter undergoes large changes in cloud structure and flow patterns over periods of hundreds to thousands of days. Thus STARLAB observations would tend to complement rather than duplicate results obtained from non-orbiting planetary spacecraft.

All of the comments which apply to the study of cloud motions in general apply equally well to the study of features of special interest, such as the Great Red Spot, South Equatorial Belt disturbances and the North Temperate Belt (southern component) zonal jet. The activity associated with these and various other interesting atmospheric phenomena is often ephemeral in nature, and can easily be missed during the short time interval of near encounter in a fly-by mission.

High resolution imaging of Jupiter in the 9800 Å absorption band of CH_4 would provide useful information on individual cloud heights. Similar photography in the 2200 Å absorption band of NH_3 would give the planet-wide distribution of ammonia in the Jovian upper atmosphere. The response of the vidicons which will fly on Voyager is such that neither of these bands can be observed.

Imaging of Jupiter at wavelength shortward of 300 nm would give the temporal and spatial distribution of ultraviolet absorbing aerosols in an otherwise Rayleigh scattering atmosphere. The shortest wavelength at which Voyager pictures can be taken is about 3000 Å, although the Voyager photopolarimeter can obtain line scans down to approximately 1800 Å.

Imagery of the Jovian system in the far ultraviolet (1000-2000 Å) would be of particular interest, because of the capability to observe the resonance emissions of atomic hydrogen (Lyman α, 1216 Å) and of other common atoms and molecules, e.g., O (1304 Å), N (1134, 1200 Å), etc. These would reveal details of the composition and morphology of gas clouds associated with the Jovian satellites, and of the intensities and spatial distributions of auroras and solar XUV- excited atmospheric day glow emissions from Jupiter and the Galilean satellites. Because of the low intensities and diffuse nature of these emissions, they would probably best be observed with the f/15 direct imaging camera (without corrector) or a slitless imaging spectrograph.

Other planets: Resolution ranges from 75 km for Mercury to 2200 km for Neptune. The scientific programs contemplated are similar to those already outlined.

Comets. STARLAB wide field high resolution imagery of comets in narrow spectral bands will give the scale lengths which are the key to coma chemistry. These observations of fine structure will give production rates for molecules and help determine the place and physics of plasma production. While many comets should be available to STARLAB during its operational lifetime, clearly a mission designed to observe the closest approach of Halley's Comet in April 1986 would be most desirable. The resolution on Halley's Comet will be better than 100 km.

2. Spectroscopic Programs

Useful spectroscopy can be done by STARLAB at both ultraviolet and infrared wavelengths. Ultraviolet spectroscopy would give the distribution of hydrogen around Jupiter and Saturn, Io and Titan, also comets and other solar system objects. It would also give isotopic abundances (H/D) at H Lα and D Lα. Also of great importance are observations of other resonance emissions, such as those of Ar, N, O, C, CO, H_2, N_2, OH and others. A faint-object imaging spectrograph (retaining spatial resolution along its entrance slit) would be particularly useful for such observations, but a high-resolution spectrograph would be necessary for some measurements (e.g., determination of temperatures from the rotational distributions in auroral H_2 emissions on Jupiter). Only very low resolution, non-imaging UV spectrometry will be carried out in the Voyager and Galileo missions. An imaging spectrograph would be very helpful in solving the parent molecule problem in comets where the high spacial resolution would allow observation of short-lived species.

Electronic transitions in biologically important organic molecules occur in the spectral region from 2000 Å to 3000 Å. A search in the atmospheres of Jupiter, Saturn and Titan for such molecules would be a crucial step in determining whether or not chemical or biological evolution of organic molecules has taken place on these outer solar system bodies.

Although Fourier spectroscopy of the plants in the near infrared (1 to 4μm) can be accomplished from the NASA C141 infrared observatory, it is found that angular resolution is quite poor due primarily to turbulent air flow over the observing window. Such measurements are not planned for ST for any current planetary spacecraft. Therefore, high angular resolution IR spectroscopy from STARLAB will be highly desirable.

3. Operational Considerations

It is unlikely that a 7-day STARLAB mission would be dedicated entirely to solar system observations. Therefore, such an observing program has not been formulated, but, instead a "typical" planetary direct imaging observing program which might be carried out daily during a STARLAB mission has been itemized.

It is assumed 2 filter wheels are employed, one containing 4 polarizers and a clear aperture, the other, approximately 8 color filters. As an example, the color filters might include four broad-band (500 Å band-pass) filters centered at 2500, 4500, 6500 and 8500 Å and four narrow-band filters isolating prominent bands of methane, ammonia, ozone and pyroxene. It is further assumed that an observation of the five bright planets with a broad-band filter requires roughly 1 minute* and that an observation through a narrow-band filter requires roughly 2 minutes.

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* This time includes operational set-up time and also envisions multiple exposures. Actual exposure times should be a fraction of a second for wide band filters. For example, if the planetary camera operates at f/60 and has a 10% quantum efficiency, the exposure for a 500 Å bandpass should be about 10^{-2} seconds for Venus, 10^{-1} seconds for Mars and 0.5 seconds for Jupiter. These exposures are sufficiently short to prevent loss of resolution due to motion of the planet relative to guide stars.

If it is also assumed that each bright planet will be observed once every 24 hours with two of the narrow-band filters, with each broad-band filter by itself and, finally, with the 4500 Å filter and each of the polarizers, an observing time of 12 minutes per planet is reached. Thus, observing all five bright planets once each day would require roughly 90 minutes (60 minutes plus maneuvering and set up time), i.e., about 6% of the total observing time. Similar observations of Uranus and Neptune will require considerably longer observing periods, but would presumably be carried out less frequently.

D. OTHER APPLICATIONS

STARLAB is intended to be a multiple user facility which will be used by many principal Investigators who are expected, through the Announcement of Opportunity process, to develop focal plane instruments. The availability of STARLAB will undoubtedly result in proposals to develop most of the types of focal plane instruments now common to all observatories. A repertoire of photometers, polarimeters and spectrometers will not only open research areas which are not available to facilities such as ST (e.g., the 912 to 1100 Å spectral region), but will also relieve the burden of inevitable oversubscription of ST by providing a means to pursue problems which do not require its full capabilities. Futhermore, since STARLAB accomodates several instruments on each mission, it can service experiments which might be considered too risky for free flyer operations. The failure of a developmental detector or of a complex experiment would not jeopardize the success of a mission, since other focal plane instruments could easily make use of the additional observing time. This flexibility is due in part to the presence of the mission and payload specialist who will also make feasible experiments which require frequent and immediate operator intervention.

Sample Scientific Instruments

The Facility Definition Team has considered several of the standard observatory instruments in some detail. These include a low resolution spectrophotometer-spectropolarimeter, a moderate resolution spectrograph, and an imaging nebular spectrometer. The Team did not attempt to prejudge the directions which will undoubtedly be taken by developers of more speculative instruments, however Fourier transform spectrometers and mosaics of solid state detectors are examples of these which were frequently mentioned.

1. Low Resolution Spectrophotometer-Spectropolarimeter (LRSP)

The LRSP was envisioned as either a Monk-Gillison or Wadsworth monochromator which would yield spectral purities on the order of 10 Å with virtually complete spectral coverage being provided by interchangeable gratings and array detectors. Conversion of the device to a spectropolarimeter would be accomplished by the Nordsieck technique in which a polarizing prism is combined with a pair of wave plates of different retardations (a Lyot "depolarizer") in a post-aperture filter wheel. The device impresses upon the spectrum a modulation, the Fourier components of which are directly related to all of the Stokes parameters which are obtained with a spectral resolution of roughly 50 Å. The device would be able to determine the absolute spectral energy distribution of a wide variety of astronomical sources with precisions of 1 percent or better. These data could be collected in a single exposure of 30 minutes (one orbital contact with a typical object) for unreddened early-type (07) stars of V=15 or V=10 at a reddening corresponding to E=1.0. All such observations could be conducted during the sunlit portion of the orbit and would thus not conflict with the direct imaging camara operations.

Among the scientific projects illustrative of those which might be pursued with the LRSP, are the following. Code has shown it to be of the utmost importance in determining the bolometric luminosities of early-type stars to include all of the energy in the immediate vicinity of the

Lyman limit in the measurements. The inclusion of the LRSP on a STARLAB flight on which LiF coatings were used could accomplish this on a far wider variety of objects than could a smaller instrument. The studies of the variations in the interstellar extinction and their correlation with other characteristics of the interstellar medium could be vastly extended over those studies conducted with OAO 1, TD 1 and ANS. Mezgar has shown that the wavelength dependance of the polarization across the 2200 Å feature can place strong limits on the origin of the feature and on the nature of the grains.

2. Moderate Resolution Spectrograph

The moderate resolution spectrograph would most likely be an echelle system giving a wavelength resolution in the 0.1 Å to 1 Å range. Its design should emphasize high efficiency rather than high photometric accuracy, so that stars in the 8th to 15th magnitude range could be observed with reasonable exposures. The scientific programs which it would accommodate include the following: abundance studies of horizontal branch stars in globular clusters and the galactic halo, abundance versus luminosity and position studies of blue giants and supergiants in the Magellanic Clouds, spectroscopy of components of close binary stars, studies of the ultraviolet spectra of old novae, dwarf novae and flare stars, ultraviolet studies of magnetic variables and peculiar A stars, etc. Scaling from study results for ST, we estimate the following limiting magnitudes for spectroscopy in the visible (corresponding limits for ultraviolet spectroscopy are a function of spectral type). These assume a 1 Å match to a single 30μm pixel, an overall system efficiency of 1% and a 10^4 seconds integration time.

Standard Deviation	Limiting V Magnitude
10%	18.4
5	17.0
3	15.9

3. Nebular Spectrometer

The extended wavelength range, large field of view, high resolution and high sensitivity of STARLAB are particularly well suited to long slit nebular spectroscopy. A program of prime interest would be the study of UV emission lines from supernova remnants, which are typically much larger than ST's field of view.

Although X-ray emission is more useful in studying the physical nature of very young remnants, ultraviolet and optical lines are very useful in studying the older and cooler remnants. As an example of the value of ultraviolet data, we can measure line ratios of transitions which occur in the same ion. Thus the ratio of the total flux in the {Ne IV} 1609 Å, 1608 Å lines to the total flux in the {Ne IV} 2441 Å, 2438 Å lines is a measure of the temperature of the gas in which the ions are located. The line ratio of the {Ne V} 1575 Å and the {Ne V} 3346 Å, 3426 Å lines yield similar information. On the other hand, the ratio of the flux in the {Ne IV} 2441 Å line to that in the {Ne IV} 2438 Å line is a sensitive indicator of the gas density. In the far ultraviolet, two of the most important lines which should be looked for are O VI 1031 Å and Ne VI 1060 Å, which are formed at intermediate temperatures, 3.2 to 5 x 10^5 °K, and are comparatively strong.

It is also important to determine ionic abundances, in order to accurately understand the details of the shockwave theory and the overall heating effect of the supernova on the interstellar medium.

Crucial to these measurements is knowledge of the interstellar extinction between the remnant and the observer. Intensity ratios between auroral and transauroral lines are useful for this purpose. Examples of such ratios are {O III} 2321 Å, 2332 Å/{O III} 4363 Å; {Ne V} 1562 Å, 1574 Å, 1592 Å/{Ne V} 2975 Å; {Ne IV} 1609 Å/{Ne IV} 4715 Å; 4725 Å {O II} 2470 Å/{O II} 7319 Å, 7330 Å; {N II} 3063 Å, 3070 Å/{N II} 5754 Å; {Ca V} 2412 Å/{Ca V} 3996 Å. Ideally, this information would be supplemented by photometry of hot stars in the neighborhood of the remnant.

4. Filter Photometer

Filter photometry is an obvious general purpose application of any telescope. By sacrificing spectral resolution, broad band photometry is able to provide greater photometric accuracy, and can reach much fainter stars or finer time resolutions than available from spectrophotometry. It is probable that scientific programs for such an instrument as STARLAB would include high-accuracy ultraviolet photometry of barely resolved globular cluster stars and binary stars, refined follow up color data on newly discovered blue halo stars, QSO's, etc., and rapid photometry over a wide wavelength range of QSO's, pulsars, rapid variable stars, and planetary and lunary occulations of stars and satellites. STARLAB's capabilities are such that the burden of all but the most critical UV photometry can be removed from ST.

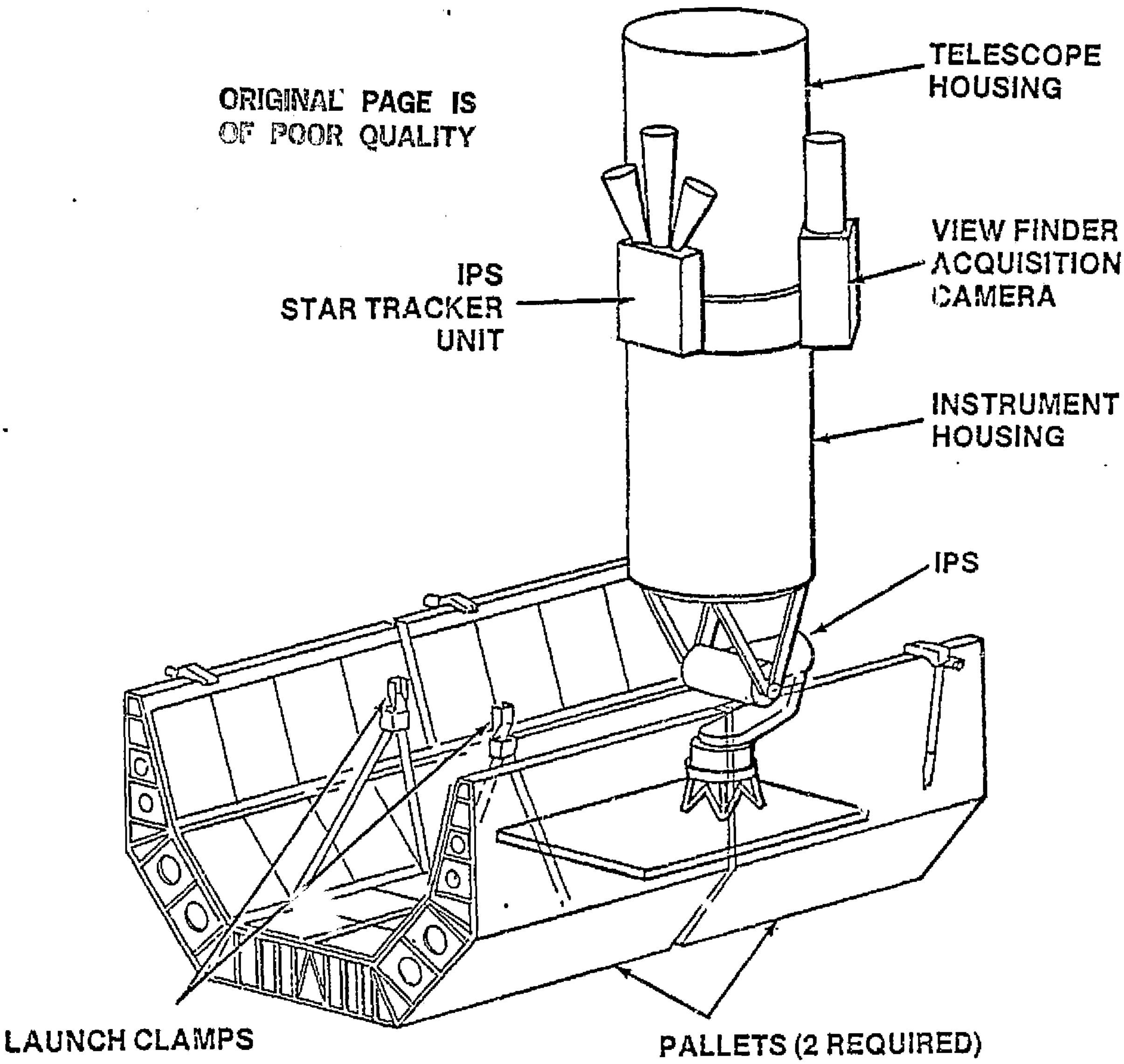
IV. STARLAB TECHNICAL DESCRIPTION

To achieve the scientific objectives an optical system was defined offering high quality imagery to the science instrumentation. Many considerations were evaluated prior to the selection of the telescope presented here and all of the telescope designs are included in the Phase A references.

A. GENERAL

The STARLAB facility consists of a 1-meter aperture f/15 modified Ritchey-Chretien telescope, followed by an instrument selector, which gives access either to the conventional cassegrain focus or, by inserting a diagonal mirror, to a radial focal plane. STARLAB is comprised of two major sections, the telescope, and the instrument bay, which are joined together at a central ring and to the European Space Agency (ESA) provided Instrument Pointing System (IPS) as shown in the figure below.

When stowed in the Shuttle-payload bay, STARLAB is supported directly from the pallets by launch clamps attached radially at the facility C.G.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VIEW FINDER
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CAMERA
IPS
STAR TRACKER
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PALLETS (2 REQUIRED)

STARLAB

B. DESIGN FEATURES

The primary driving goal of the STARLAB design has been to achieve wide field imagery of at least 0.5° FOV with high resolution. An optical design study recently concluded has proved conclusively that STARLAB's specifications can be met with a cost effective design. A direct-imaging wide field camera will be a semi-permanent fixture.

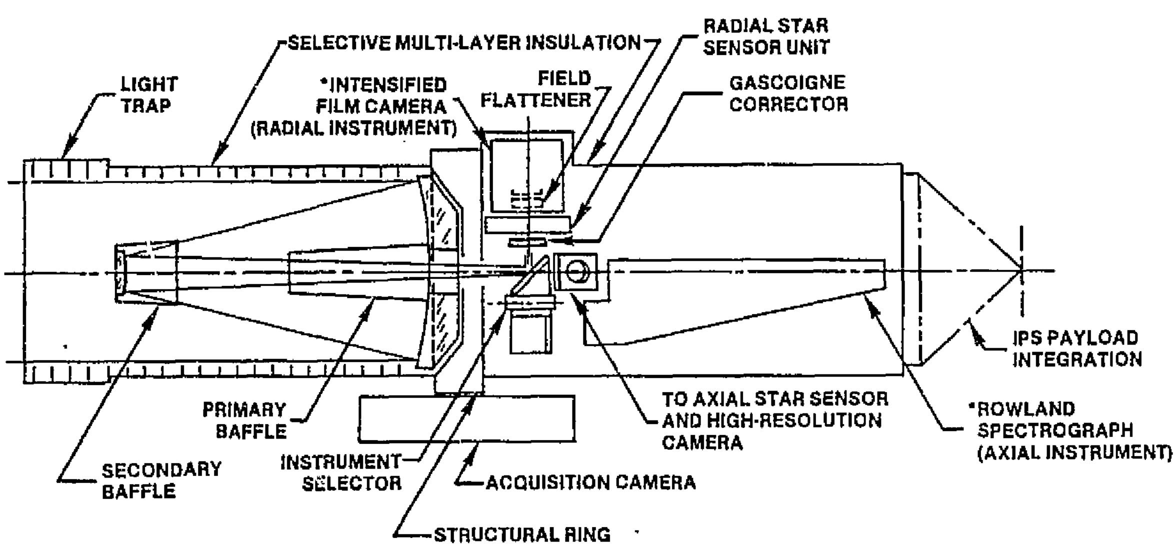
Although STARLAB will be a highly automated facility capable of performing many assignments that have been pre-programmed, having scientists available on-board assures that high efficiency and quick-reaction capability will be achieved. The facility design includes a star field presentation to on-board scientists as well as real-time pointing control and instrument operations.

STARLAB has been designed for compatibility with all phases of Mission and Science Operations:

- A standard mounting base has been incorporated for the PI-provided instruments.
- The structure has been designed to survive, without fatigue, a minimum of twenty mission cycles. Alignment will not be required upon deployment.
- STARLAB structural and optical modular design provides for the replacement and recoating of the optical surfaces to optimize the spectral response for specialized STARLAB missions
- The telescope will be provided with a seal and purge protective system of dry N_2 or similar for active contamination control.
- For command and data transfer, STARLAB is compatible with and will make maximum use of Spacelab-provided electronic interface units

C. TELESCOPE

STARLAB consists of a forward telescope housing and an aft instrument housing joined at a main, common annular structural ring. This central structural ring serves to mount the primary mirror, and also to provide the attaching points and indexing surfaces for the scientific instruments, the fine guidance sensor, the focus sensor, the instrument selector, and other permanent fixtures of the facility. Surrounding the fore and aft structural housings is selective multi-layer insulation for thermal control of the STARLAB instruments and subsystems. STARLAB is integrated to the Image Pointing System (IPS) by means of a two-bay truss structure within the aft instrument housing which supports and transmits the telescope load from the main structural ring to the Payload Integration Plate.



•ILLUSTRATIVE FOCAL PLANE INSTRUMENTS

D. STATE OF TECHNOLOGY REQUIRED

At every stage of the evolution of the STARLAB program including the feasibility phase and the current design studies, the use of proven technology, within the state-of-the-art, has been stressed. These guidelines have applied equally to the telescope optical design, tracking and guidance control, and to the initial strawman complement of scientific instruments. New development is neither contemplated nor required for the initial facility. It is worth while to mention that current independent advances in detector technology will provide options for both guidance/tracking and scientific instruments during the procurement and development phases of STARLAB.

The metering shell forward of the main structural ring, housing the telescope main components, is to be fabricated as a graphite-epoxy cylinder of monocoque construction. This technique has been successfully employed on other large space-designed telescopes. The remainder of the telescope structure is comprised of aluminum to minimize cost. There is both adequate weight margin in the design and tight active thermal control to employ aluminum over other more exotic and costly materials.

Both the primary and secondary mirrors will be solid Cervit or ULE. Again the weight margin allows the use of standard and solid materials in lieu of honeycomb structures or metal optics. A coating of aluminum, overcoated with magnesium floride has been recommended as the nominal coating for the telescopes for use in the primary STARLAB UV spectral range. Lithium overcoated mirrors can be considered to extend the spectral range of usefulness of the telescope shortwards to about 900 A. However, these coatings are difficult to maintain and will require special environmental precautions.

Photographic film has been selected as the primary data recording medium for the high resolution Science instruments. Film is particularly applicable for the sortie-missions and offers proven techniques for high-resolution imagery.

The choice and selection of detectors has been considerably broadened by recent development, especially with CCD matrix techniques. The spectral response has been pushed shortward into the UV region and Quantum efficiencies over the entire spectral region of interest have been improved. Electrographic cameras have been developed which will allow instruments, especially the wide field direct imaging camera, to employ this technique.

E. STARLAB SPECIFICATIONS

Size:	5m length x 1½m diameter
Mass:	2000 kg (includes 500 kg for focal plane instruments)
Mirror coatings:	Nominally Al + MgF_2 optimized for 1150Å to 30,000Å Optionally Al + LiF optimized for 910Å to 1200Å
Diameter of flat field:	0°5 with focal plane correctors 0°1 without correctors
Image diameter: (70% encircled energy)	0.3 arcsec over 0°5 corrected flat field diameter @ 2500Å to 8500Å 0°1 uncorrected flat field diameter @ 900Å to 8500Å 0°2 uncorrected curved field diameter @ 900Å to 8500Å
Angular resolution (50% modulation)	30-33 cycles/mm 2.2-2.4 cycles/arc-sec. 0.40-0.45 arc-sec resolution
(Rayleigh Criterion)	100-120 cycles/mm 7-9 cycles/arc-sec. 0.12-0.14 arc-sec resolution
Baffling:	Full baffling of both science and tracking fields
Focal plane viewing:	Operator able to view both science and tracking fields for target acquisition
Guiding system:	Two focal plane sensors provide image stability to ±0.03 arcsec (1σ)
Power:	One kw average (includes 350 watts for focal plane instruments)
Thermal Control:	The primary operating temperature will be 20°C. Active Thermal Control will be sufficient to prevent significant change in focus over an interval of 10 hours. The scientific instrument environment temperature will be 20°C ±10°C.

F. OPTICAL DESIGN

The telescope comprises two mirrors, primary and secondary, both of which are hyperbolas. Being pure conic sections, they require no aspheric deformations. The primary mirror is concave; the secondary is convex. The conic constants are obtained by the simultaneous solution for zero spherical aberration and coma. The primary is f/2 and the secondary is f/2.04, while the overall system f/number is f/15, which requires a secondary magnification of 7.5. The resulting system, when baffled, has approximately a 0.35 linear obscuration ratio and provides a 48 arc-min FOV with a gascoine corrector. This field of view is divided with 0.5 degree to the Wide Field Camera and the remaining 0.3 degree annulus for fine pointing and tracking, but this may be varied in practice. Fields of view in excess of the 0.8 degree diameter are available but only with ever increasing vignetting due to the baffling of the system.

Since the system is all-reflective, it has no wavelength dependence and will perform, essentially unchanged, for any wavelength of light within the operational range for 120 nm to 3 μm. However, aperture diffraction is wavelength dependent and will be considered, as it will affect the quality of the final image.

G. FOCAL PLANE INSTRUMENTS

It is expected that STARLAB will permit the use of a wide variety of focal plane instruments. Most of these will be designed and built by scientists interested in particular scientific objectives and as a result of A.O.'s. In order to arrive at a compatible design for the telescope and conceptual scientific instruments, ten candidate instruments have been identified and studied.

To allow the use of multiple instruments the facility instrument selector can be indexed on command to accept scientific instruments positioned at the axial focal plane or at one of the radial focal plane locations. The "radial" instruments will receive the telescope image via a diagonal mirror whereas an "axial" instrument will receive the image without a folding mirror. The number of instruments at the axial focus is not always limited to one. For many instruments, an off-axis slit position is acceptable, since the telescope astigmatism can usually be corrected by the instrument optics. Two "axial" instruments may then be placed adjacent. The facility includes, as a permanent fixture, an external viewfinder telescope intended primarily for inspection of the data field and for verification of acquisition.

Among the instruments suitable for mounting at the axial focal plane are:

- Far-UV Rowland Spectrograph
- Far-UV electrographic camera
- High-precision spectrophotometer-polarimeter
- Nebular spectrograph

These are instruments either of great length (upper limit 1.5m) or instruments for which a minimum number of reflections is essential.

The radial focal plane is primarily intended for smaller instruments (typically 0.6m by 0.6m by 0.5m) operating at wavelenghts above 120nm, such as:

- Intensified-film camera
- Electrographic camera
- Direct-photography camera
- Broad-band photometer
- Fourier spectrograph

Another instrument intended to be flown on most, if not all, missions is a 1.5 min of arc field, high-resolution camera. The main purpose of the latter is to conduct regular synoptic planetary observations. It receives the telescope image by means of a small, permanent, off-axis folding mirror near the axial focus.

H. POINTING CONTROL SYSTEMS

STARLAB will be pointed by means of the Instrument Pointing System (IPS) under development of SPACELAB. The IPS is hard-mounted to one of the SPACELAB pallets and is connected to STARLAB through the Integration Payload Plate and the Main Structural Ring Assembly. The IPS three-axis servo will be directed by the Payload Specialist (PLS) during the target acquisition sequence and will function closed-loop during the target observation period.

Residual pointing errors of the STARLAB facility are reduced by means of an Internal Motion Compensation (IMC) system that articulates the secondary mirror.

As presently envisioned, separate IMC guide-star sensors are available for each of the focal planes. This assures accurate reacquisition if the two instruments are used alternatively in the same mission. The IMC sensors are located in an annular field surrounding the data field. An additional IMC roll sensor is necessary to link the guide star and target positions. This roll sensor is common to all instruments and is mounted outside the telescope, at 90° to the telescope axis. A field-of-view diameter of about 1° suffices to assure adequate probability for the presence of a suitable guide star.

I. COMMAND AND DATA MANAGEMENT

The STARLAB facility will interface with the Shuttle and SPACELAB through the standard Remote Acquisition Units (RAU) and the High Rate Multiplexer (HRM). All of the commands, telemetry and dedicated experiment processors will be accomodated by three RAU. The science data will be transmitted via the HRM. The STARLAB facility and instruments will be commandable from the PLS station or remotely from a Science Operations Center. Pertinent science data, engineering telemetry, and command sequences will be displayed at the appropriate control consoles.

A STARLAB Command and Data Handling (C &DH) subsystem, as part of the facility, will comprise hardware and software to:

- Respond to and process commands, real time and stored
- Provide appropriate engineering telemetry
- Monitor and manage the electrical power
- Convert analog signals to digital
- Multiplex the data outputs.

V. STARLAB PHASE B STUDIES

STARLAB study efforts to date have been structured in two phases. Six Phase A studies, the last completed in 1977, have explored conceptual definition, optical system design, systems feasibility and related topics. Five Phase B studies, extending the concepts established in the Phase A effort, have been recently completed (1978). These five are:

A. Optical Subsystem Design
B. Instrument Conceptual Design
C. Structural-Thermal Subsystem Design
D. Acquisition and Tracking Subsystem Design
E. Command and Data Handling Subsystem Design

Phase B study effort was to culminate in the sixth and last study:

F. Facility Systems Definition Design

A facility systems design effort would incorporate the previous results into a complete systems definition phase study. The necessary and preliminary preparations for release of an RFP for the Systems Definition Design Study were completed in August 1978. The study will not be released at this time at the request of NASA Headquarters. The Facility Systems Definition Design Study Statement of Work (SOW) is included as Appendix A in Volume II.

A. OPTICAL SUBSYSTEM DESIGN STUDY

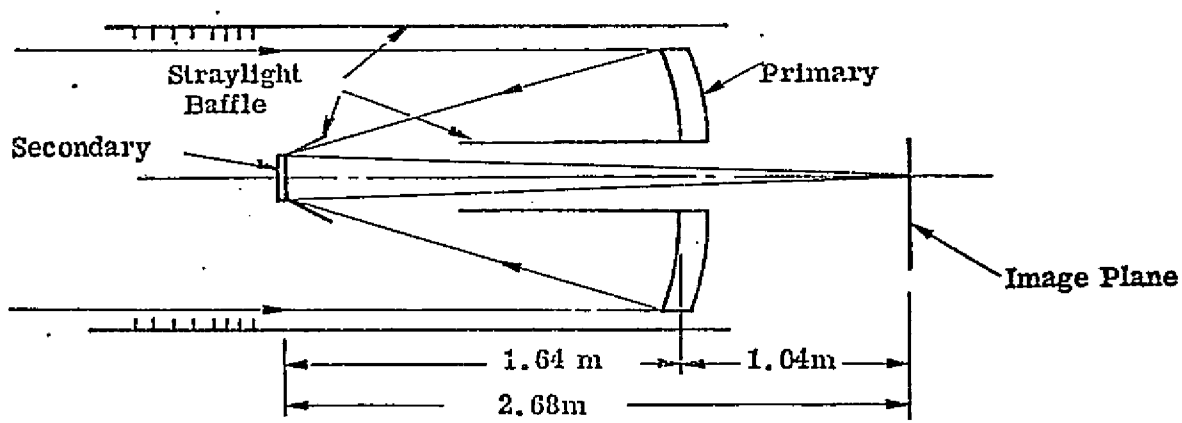
Perkin - Elmer, March 1978

1.0 INTRODUCTION

The purpose of this study was to define and execute a telescope optical subsystem design for Starlab. The principal results of this effort are an optical prescription, performance analyses, optical tolerances, subsystem-to-subsystem interface requirements, and manufacturing requirements. A detailed optical design was completed that included design optimization evaluation and sensitivity analysis, subsequent tolerance allocation, toleranced performance analysis, baffle/stray light analysis, and computer modeling of the final design.

2.0 TELESCOPE OPTICAL DESIGN

The final optical design of the Starlab Ritchey-Chretien telescope is shown in Figure 5-1. The telescope comprises two mirrors, primary and secondary, both of which are hyperbolas. The primary is f/2 and the secondary is f/2.04, while the overall system f/number is f/15, which requires a secondary magnification of 7.5. The resulting system, when baffled, has approximately a 0.35 linear obscuration ratio and provides a 48 arc-min field of view. This field of view is divided with 0.5 degree to the Wide Field Camera and the remaining 0.3 degree annulus is allocated for fine pointing and tracking. Fields of view in excess of the 0.8 degree diameter are available but only with ever increasing vignetting due to the baffling of the system. The optical prescription is shown in figure 5.2.



Element

- Primary — ULE/Cervit Hyperbola, 4.00 Radius, 2.00 EFL, 1.0 Aperture, f/2
- Secondary — ULE/Cervit Hyperbola, 0.825 Base Radius, 7.5 Magnification, 0.2 Aperture, f/2.04

System

• Aperture	1.0 m
• Focal Ratio	f/15
• Linear Obscuration Ratio	0.35
• EFL	15.0
• Back Focal Length	1.04 m
• Plate Scale	15.0 mm/mrad (4.36 mm/arc-min)
• Field of View Diameter	0.8° = 48 arc-min = 13.96 mrad
• Data Field Diameter	0.5° = 30 arc-min = 8.73 mrad
• Tracking Field Size	1.44×10^{-4} sr = 1.70×10^{3} (arc-min)^2
• Coating	500Å to 800Å al w/250Å MgF
• Wavelength Range	120 nm to 1 μm
• Spatial Resolution (at 633 nm)	0.73 μrad (0.15 arc-sec) Rayleigh
• Encircled Energy	60% in 0.3 arc-sec

FIGURE 5-1. STARLAB OPTICAL DESIGN

NO.	SURFACE	RADIUS	THICKNESS	MD-INDEX	HI-INDEX	LO-INDEX	GL.NAME	1ST.BNDY	2ND.BNDY
WAVELENGTH				0.63280	0.63280	0.63280		PHI	0.0
			0.0	1.00000	1.00000	1.00000			
1	ASPHER.	-4000.0000	-1642.5000	-1.00000	-1.00000	-1.00000	AIR	1000.44	0.0
2	ASPHER.	-825.0000	1642.5000	1.00000	1.00000	1.00000	AIR	202.41	0.0
3	SPHER.	INF	1038.7500	1.00000	1.00000	1.00000	AIR	206.10	0.0
4	SPHER.	INF	0.0002	1.00000	1.00000	1.00000	AIR	210.60	0.0

TABLE OF ASPHERIC COEFFICIENTS

NO.	E	A(4)	A(6)	A(8)	A(10)
1	-8.004919D-03	0.0	0.0	0.0	0.0
2	-7.788538D-01	0.0	0.0	0.0	0.0

FIRST ORDER PARAMETERS ON MERIDIONAL PLANE

OBJECT DSTNCE	ENTR.PUP.DIST	FRST.PPAL.PNT	EQV.FCL.LNGTH	SCND.PPAL.PNT	EXT.PUP.DSTNC	IMAGE DISTNCE
INF	0.0	-59727.271943	14999.999829	-13961.249692	-1972.198906	1038.750138
OBJECT HEIGHT	ENTR.PUP.SIZE	OBJT.SPCE.FNO	TRACK LENGTH	IMGE.SPCE.FNO	EXT.PUPL.SIZE	IMAGE HEIGHT
INF	999.999989	INF	INF	15.000000	200.729925	104.721455
MAGNIFICATION	SEMIANG.FIELD	BACK VTX.DIST	BARREL LENGTH	FRNT.VTX.DIST	SEMIANG.FIELD	DEMAGNIFICATION
0.0	0.400000	INF	0.0	1038.750138	1.992727	INF
APT.STOP SIZE	APT.STOP DIST	FROM SRFCE.NO	************	FLD.STOP SIZE	FLD.STOP DIST	FROM SRFCE.NO
999.999989	0.0	1		209.442911	1038.750138	3

Surface Equation

```
                 1
            C*(y**2 + z**2)
 X   =   -------------------------------------   +
         1 + SQRT(1 - e<y>*C**2*(y**2 + z**2))
                         6   1

           7                    8
           C'*(y**2 + z**2)**2 + D'*(y**2 + z**2)**3  +

           9                    10
           E'*(y**2 + z**2)**4 + F'*(y**2 + z**2)**5
```

Figure 5-2. Telescope Optical Prescription

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OF POOR QUALITY

Since the system is all-reflective, it has no wavelength dependence and will perform, essentially unchanged, for any wavelength of light within the operational range from 120 nm to 3 μm. However, aperture diffraction is wavelength dependent and must be considered, as it will affect the quality of the final image.

A coating of 500Å and 800Å of aluminum, overcoated with 250Å of magnesium fluoride is recommended as the nominal coating for the telescope mirrors. Such a coating represents the best current practice with telescopes for use in the primary Starlab UV spectral range. Lithium Fluoride overcoated mirrors can be considered to extend the spectral range of usefulness of the telescope shortwards to about 900Å. However, these coating are not environmentally sound and they do not allow cleaning. Therefore, their use will prove more costly and will require special environmental precautions. For these periodic applications of Starlab where the wavelength range accessible through the use of lithium fluoride overcoats is required, these coatings can be put on the mirrors. The telescope has been designed to permit easy access and removal of the primary and secondary mirrors for cleaning and for change of coatings during its operational lifetime.

3.0 ERROR BUDGET

Perkin-Elmer began with a computation of the basic optical sensitivities of the system. Following this, an overall system wavefront error budget was established and finally the budget was allocated to the various major subsystems of the design.

The report states that the sensitivities are not severe. About half the error budget is assigned to primary and secondary mirror surfaces and the remainder to the systems structure. The total budget is $\lambda/20$ at 623.8 nm. Figures 5-3 and 5-4 give a breakdown of the major components of the optical error budget. The error components are RSS'ed together to obtain the total expected error.

4.0 THERMAL DESIGN INPUTS

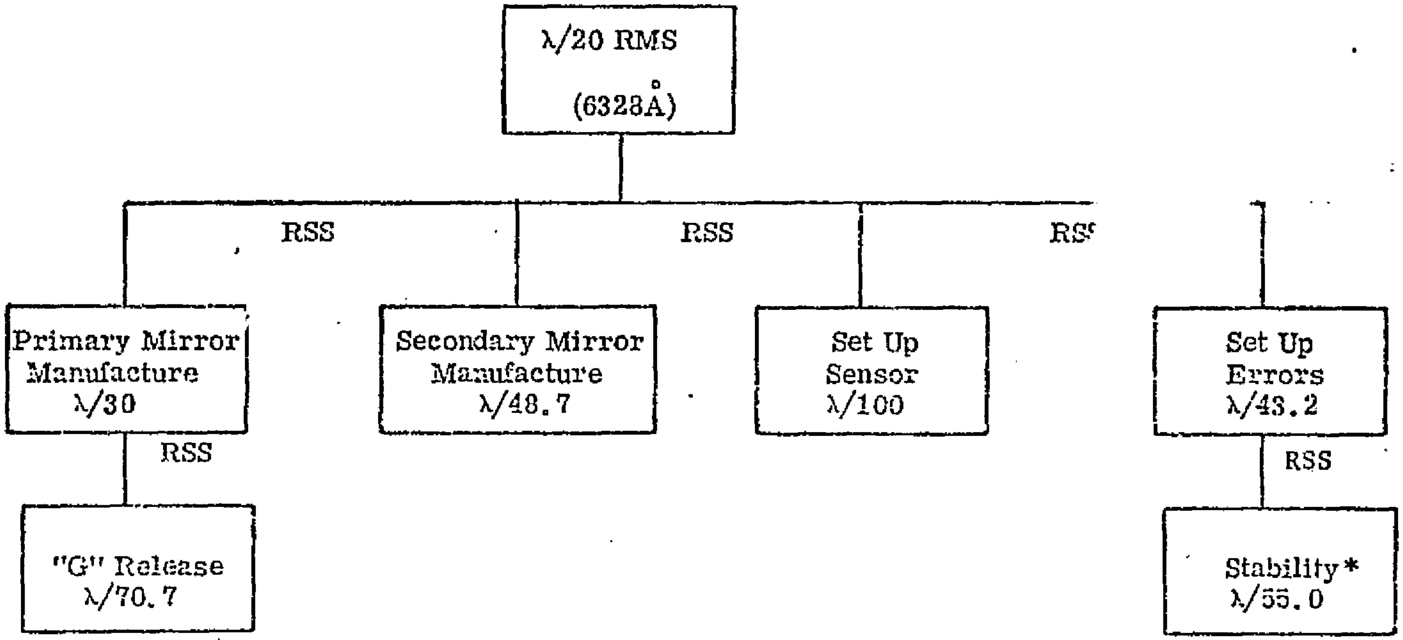
The thermal considerations of the Starlab Optical Definition Design Study were similar in depth to the structural studies. Their purpose was to assess the thermal inputs to the optical tolerance budget, provide a check on

Sensitivities: 0.0125 mm Decenter $\lambda/102.45$
7.5 Arc-Sec Tip $\lambda/101.04$

Δ BF ≈ 28.23 ΔR Primary
Δ BF ≈ 12.02 Δ R Secondary
Δ BF = 57.17 Δ T Primary-Secondary Despace

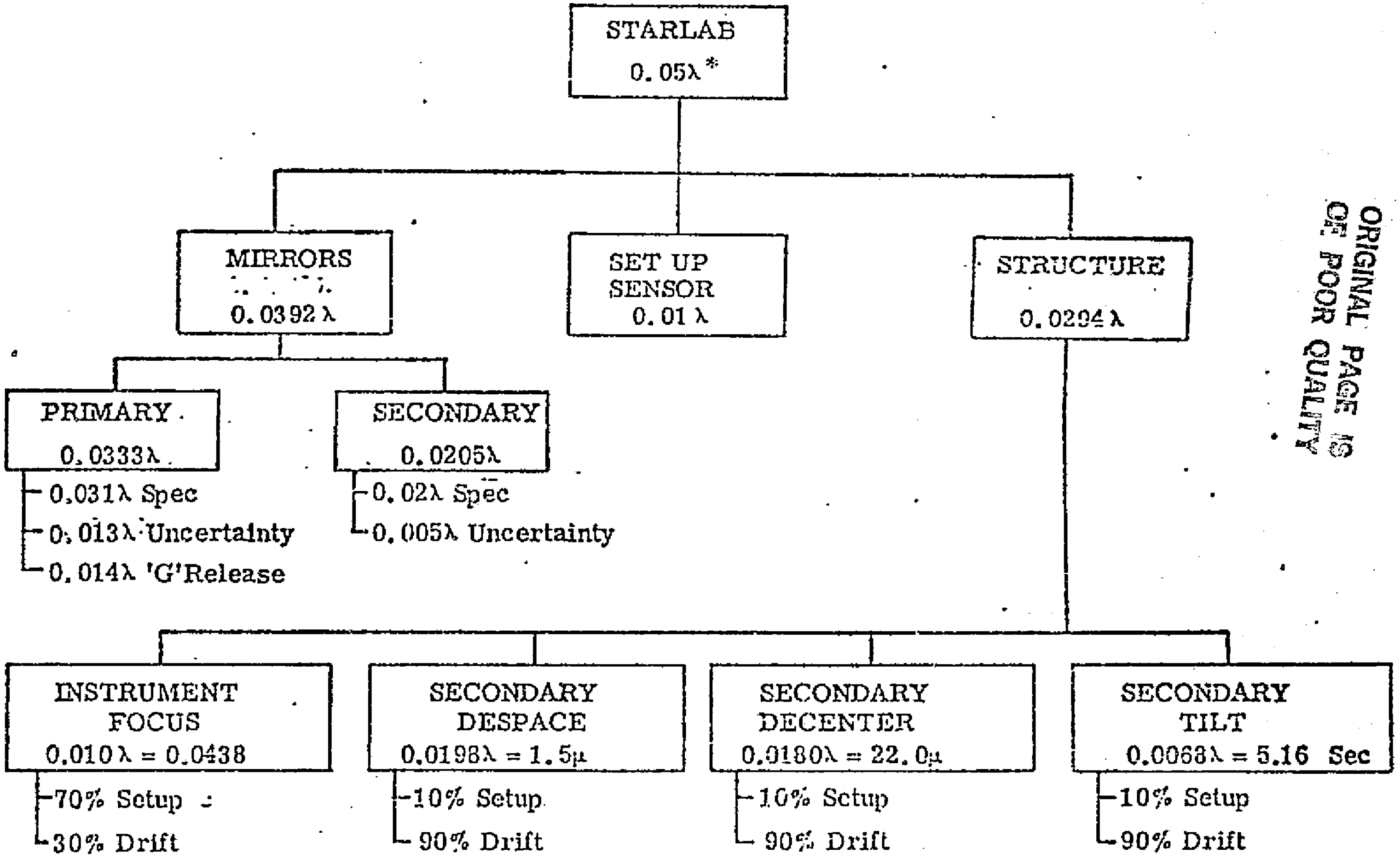
Note: $\pm$ 0.2167 mm ΔBF $\Rightarrow$ $\lambda/20$ RMS OPD

Tolerance Allocation:



* Stability includes the effects of: R Primary, R Secondary, Tip, Decenter, Despace, Tip of Focal Plane Figure (PRI), Figure (SEC), Inst. Focus,

FIGURE 5-3. STARLAB OPTICAL SENSITIVITY ANALYSIS



* λ = 632.8 nm

FIGURE 5-4. STARLAB OPTICAL TOLERANCE BUDGET the possible systemization of errors and determine whether any problems existed that required recommended remedial action.

In general, the findings on the thermal effects in the system indicated no special problems. The effects computed can be absorbed into the optical tolerance budget, with one important exception - the effect of thermal gradients and variations in expansion coefficient through the thickness of the primary mirror. These computations imply unreasonable limits of a maximum 0.18^{o}C temperature gradient through the primary mirror and a $\pm$0.75^{o}C bulk temperature maintenance requirement. These values each consume the entire focus budget of the system. Consequently, an on-orbit focus mechanism is recommended for Starlab.

5.0 ACQUISITION AND TRACKING INTERACTIONS WITH THE OPTICAL DESIGN

Throughout the design effort computations were made of the internal geometry of the Starlab imagery under various conditions of operation and under various types of tolerance build-ups. Since the fine stabilization system of Starlab is an offset pointing device, it is important that the geometry of the image between the guide stars and the data stars remain fixed. If this geometry varies during an exposure, then fine pointing errors occur.

The "secondary mirror motion", fine pointing actuation system is required by Starlab's mode of operation, tethered to the Shuttle via the IPS. This requires that internal image motions be generated and places a set of optical design constraints on the system. When using the secondary mirror to move the image it was found that large amounts of uncorrected image distortion resulted in variations of image geometry if the secondary mirror were actuated. These image geometry effects in the wide field camera occur as differential variations in distortion. They were large enough in the Phase A wide field camera Gascoigne corrector to cause undesirable size contributions to the pointing and tracking tolerance budget. The current baseline corrector design minimizes distortion adequately, rendering this effect negligible.

Along with an analysis of the higher-order effects of the accepted fine pointing and stabilization scheme, an analysis was made of the final optical design to determine the constants of the secondary mirror motion needed to obtain fine pointing. These analyses establish the ranges of motion, accuracies and recommended mirror pivot locations.

6.0 WIDE FIELD CAMERA CORRECTOR

The most significant feature of STARLAB is the wide field of view (FOV): 0.5° diameter. This FOV is achieved by a combination of a Ritchey-Chretien telescope (which cancels first order aberrations) and a Gascoigne corrector (which corrects for third and fifth order aberrations). The Gascoigne corrector will be fabricated from CaF_2 and optimized to minimize chromatic aberrations at 280 nm, and with a useful range of 215-600 nm. A fused silica (SiO_2) field flattener will be used in conjunction with the intensified film camera.

7.0 BAFFLE DESIGN

The Telescope baffle design incorporates full field baffling and is shown in Figure 5-5.

8.0 CONTAMINATION CONSIDERATIONS

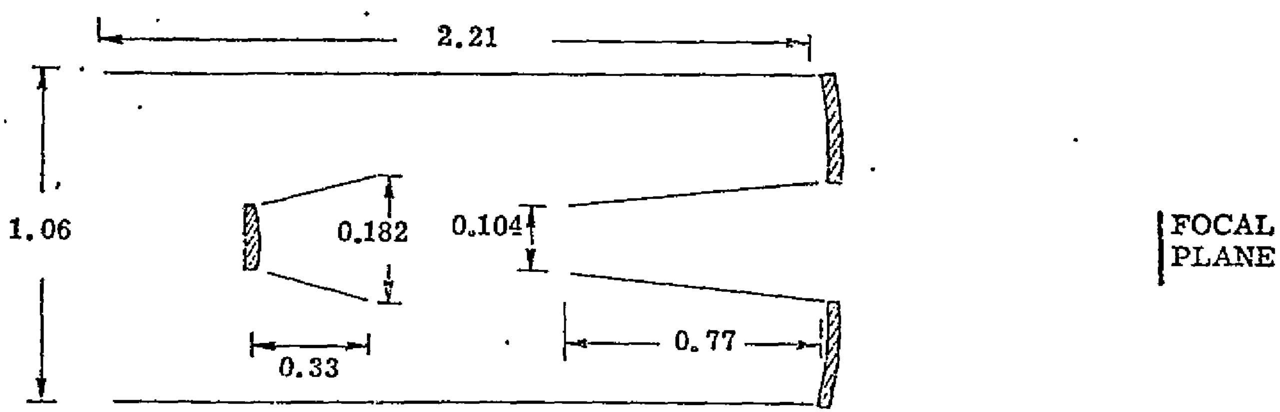
A Section and an Appendix are devoted to contamination considerations and how they affect the optical system Bidirectional Reflectance Distribution Function (BRDF). The conclusions are presented as part of Section VI of this report.

REQUIREMENTS FOR 1st ORDER BAFFLE DESIGN

(1) NO DIRECT VIEW OF OBJECT SPACE FROM FOCAL PLANE O

(2) 40% CENTRAL OBSCURATION MAX (35% GOAL)

(3) NO VIGNETTING AT EDGE OF ±0.4° FIELD



⟹ 36.4% OBSCURATION ACHIEVED

FIGURE 5-5. STARLAB BAFFLE DESIGN

B. INSTRUMENT DESIGN

Ball Aerospace Systems Division, April 1978

1.0 INTRODUCTION

The "STARLAB Instrument Design Concept Study" describes the Starlab instrument design concept and includes a description of the accommodations available to the various scientific and facility instrumentation which will be integrated into the Starlab. The "Strawman" science instruments (SI's) which are being considered for flight are described.

The report incorporates the system design changes which were recommended during the Phase B studies. The most notable of these changes recommends, and describes the capability for Starlab to have three radially positioned SI's instead of the original concept with a single radial SI. The form factor shown for the radial SI's is a rather compact 0.5 meter^3 and represents a typical electrographic camera.

2.0 GENERAL CONFIGURATION

The Focal Plane Assembly shown in Figures 5-6 and 5-7 provide accommodations for one axial SI. three radial SI's, an acquisition camera, a slit camera, and a planetary camera.

The Phase-B focal plane configuration and the various subsystems are described in detail. Much attention is given to the optical and mechanical implementation of the radial and axial fine guidance sensors (FGS). In both sensors, the F/15 telescope beam is converted to F/25 to obtain a smaller noise-equivalent angle (NEA) for the same, star-magnitude limited FGS

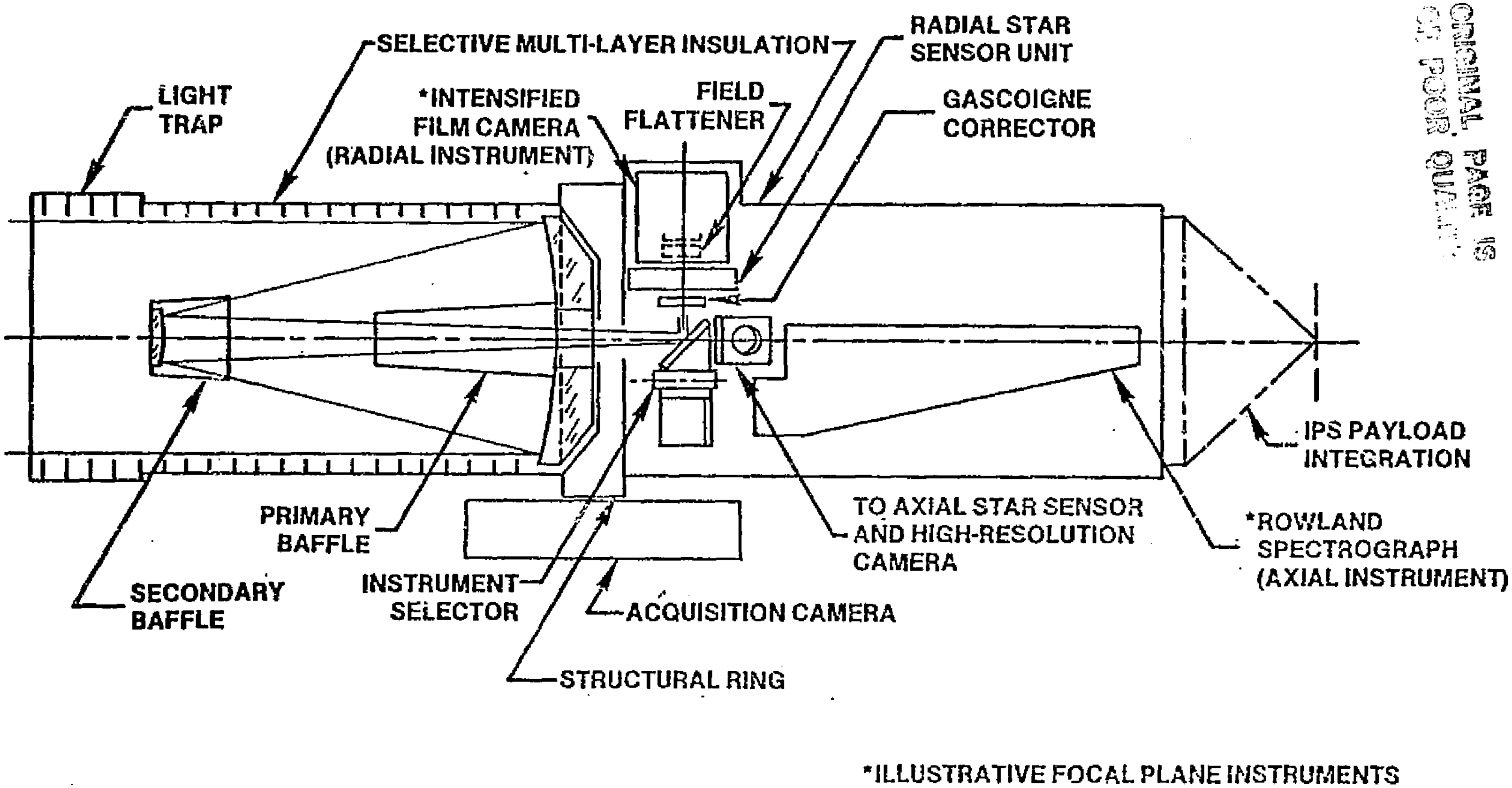


FIGURE 5-6. STARLAB WITH TWO TO FOUR MAJOR SCIENTIFIC INSTRUMENTS AND EXTERNAL ACQUISITION CAMERA

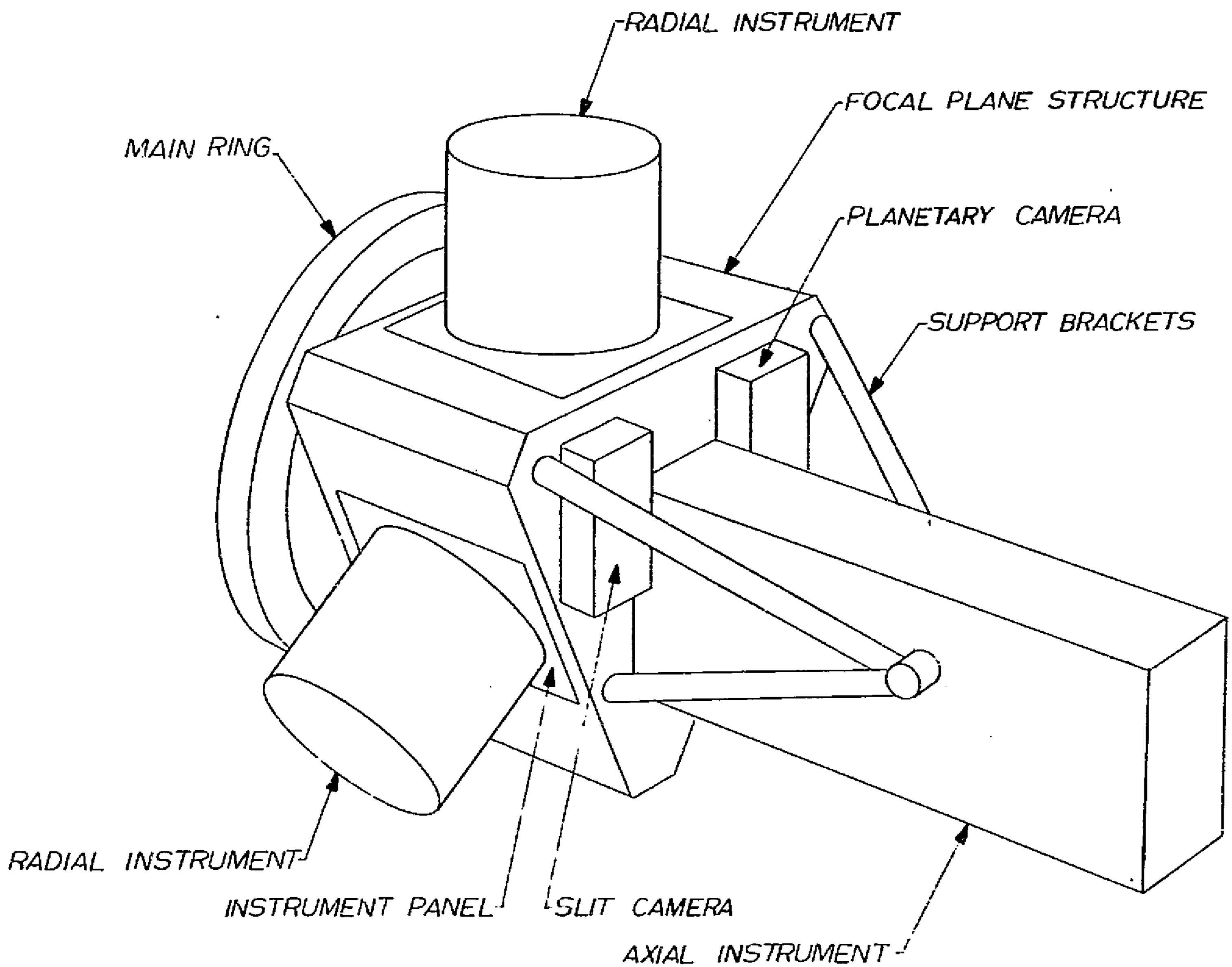


FIGURE 5-7. STARLAB, PHASE-B FOCAL-PLANE ASSEMBLY

detection accuracy. This involves relay optics, which magnify by a factor 5/3 and also compensate telescope astigmatism and field curvature. The rho-theta mechanism for the axial FGS consists of two pairs of parallel mirrors, which are rotated independently to provide radial and angular positioning. The sensor head itself is fixed. Its X and Y star-scanning directions are immune to rho and theta changes. The X and Y control signals can be sent to the secondary mirror control mechanisms by independent circuits.

The optical and mechanical design of the television camera (F/5 Schmidt-Cassegrain telescope with a 25 mm SIT camera tube) and the slit camera (F/70 relay optics, also with 25 mm SIT camera tube) is presented. The slit camera also serves as a focus sensor. The Payload Specialist (PS) can remotely move one of the relay mirrors and observe the telescope image and/or the back-illuminated axial-instrument slit on his CCTV screen.

The section on the focal plane assembly also describes the method of mounting of the scientific instruments and concludes with tables, summarizing interface parameters, i.e., sizes, masses, power requirements, and command and data handling requirements.

3.0 SCIENTIFIC INSTRUMENTS

Section 4 of the study discusses design concepts of eight "strawman" scientific instruments, defined in the SOW. The object was mainly to investigate compatibility with the STARLAB facility and to identify possible constraints. These concepts may be used as a point of reference for future PI instrument designs, but are too preliminary to be considered as recommendations. The eight "strawman" instruments are the following:

<u>Direct Imaging Camera</u>

Under this heading fall a photographic film camera (200 - 600 nm or 230 - 900 nm), an intensified photographic film camera (200 - 600 nm or 230 -900 nm or 180 - 330 nm) and a variety of electrographic cameras, useable in the 130 - 330 nm wavelength range. The latter represent a significant extension of the lower wavelength limit of 200 nm in Phase A. Either one of these cameras can be flown as a principal radial instrument, equipped with filterwheels and a FGS. Two more can serve as additional radial instruments.

<u>Planetary Imaging Camera</u>

This consists of a 4x Schwarzschild relay, producing a 40 arc sec field and telescope-limited resolution at F/60. The detector considered in this report is either a cooled, UV-sensitized CCD or an ICCD. Polarization by the pick-off mirror (at 0.25° field angle near the axial focus) is compensated by an additional internal 90° reflection. A shutter and filterwheels (including polarizers) can be accomodated.

<u>Precisely Calibrated Spectrophotometer</u>

A Monk-Gillieson and a Wadsworth configuration are compared. The latter is more compact and offers superior image quality. Either one could serve as a major axial instrument.

<u>Far Ultraviolet Spectrograph</u>

Two versions are investigated: a classical Rowland spectrograph with a mechanically ruled grating and a spectrograph with a holographic grating. The Rowland spectrograph is used in this report to define concepts for mounting of the axial instruments. It is a major driver in this design, because part of the spectrograph protrudes forward of the focal plane. Provided detectors with 15 μm pixels will be available for the 90 - 122 nm range, spectral resolutions of about $R = 4 \times 10^4$ can be realized within the STARLAB envelope constraints.

Faint-Object Spectrograph

A Wadsworth spectrograph, just small enough to be flown as a radial instrument, is identified as a candidate concept. Four interchangeable gratings would be needed to cover the 110 - 400 nm wavelength range at $R \approx 1000$.

Fabry-Perot Spectrograph

Three etalons in tandem, preceeded by a broad-band filter, are pneumatically scanned to study line profiles with spectral resolutions of the order of 10^6. Packaging either as an axial or radial instrument seems feasible.

Echelle Spectrograph

A spectrograph with a single echelle grating, a single SEC vidicon detector and four interchangeable cross dispersers is briefly described as an alternate major axial instrument. Spectral resolutions of the order of $R = 10^5$ seem possible, but image quality at F/15 may present a problem.

Fourier-Transform Spectrograph

The technical problems envisioned here are detector cooling and possible pointing disturbances from moving interferometer mirrors. However, neither should be a deterrent to application on STARLAB.

The Science Instrument Parameters and capabilities are listed in Table 5-1.

Section 5 describes a development plan and work-breakdown structures for the focal-plane assembly and a representative focal-plane instrument.

TABLE 5-1

SCIENCE INSTRUMENT PARAMETERS AND CAPABILITIES

SCIENCE INSTRUMENT	FOV	SPECTRAL COVERAGE (nm)	RESOLUTION (SPECTRAL) (λ)nm	RESOLUTION (SPATIAL)	LOCATION (OPTICAL INPUT)	SENSOR
DIRECT IMAGING CAMERA	0.5^{o}	130-900		.38 sec 85 lp/mm	Radial	Film (Intensified) (Electrographic)
PLANETARY IMAGING CAMERA	48 sec.	120-900 UV Sensitized w/filters, polarized		Diffraction Limited	Radial	CCD or ICCD
PRECISELY CALIBRATED SPECTROMETER	f/15	90-1000	10^4		Axial	Detector Array
FAR UV SPECTROGRAPH	0.01^{o}	90-122	4×10^4 ($\lambda \approx 0.022$nm)	1.4 Sec (Full Field)	Axial	MAMA
FAINT OBJECT SPECTROGRAPH		110-400	10^3		Axial or Radial	
FABRY-PEROT SPECTROGRAPH	3 min.		10^5	f/15	Axial or Radial	SEC VIDICON
FOURIER TRANSFORM SPECTROGRAPH	4.3 min	1000-4000	5 cm^{-1} @ 1000 1.25 cm^{-1} @ 4000		Radial	PbS PbSe InSb
PHOTOGRAPHIC FILM CAMERA	? LENS DEPENDENT	NONE	LOW	LENS DEPENDENT		FILM
SCANNING WADSWORTH SPECTROGRAPH	f/15	90-1000 MULTI-GRATING			AXIAL	CCD AND MAMA

C. STRUCTURAL - THERMAL DESIGN STUDY
Perkin-Elmer, March 1978

1.0 INTRODUCTION

This report describes the definition and design of the structural - thermal subsystem for the STARLAB facility. Emphasis was placed on a "cost effective" design and on the maximum use of proven parts, configuration, assembly, alignment and test. The design developed is consistent with the environments anticipated during a Shuttle launch and re-entry and with the orbital environments anticipated during the Starlab mission. These orbital environments include consideration for external and internal thermal loadings as well as Shuttle and Starlab induced vibrational disturbances which will be transmitted to the telescope. The design is based upon specified optical alignment tolerances. These conditions are maintained from initial assembly and through all operational modes. Tolerances include considerations for effects of launch; "g" release, thermal and vibrations (ground and orbital).

Table 5-2 presents the Structural Tolerance Allocations.

2.0 ANALYSES AND DESIGN STUDIES

This section presents the Starlab telescope structural analyses and design studies. First the design requirements for the telescope are enumerated, and then, the resultant design, meeting these requirements, is described. The tradeoffs which were performed to arrive at the design are then discussed. The preliminary and detailed analyses conducted to size out the element of

TABLE 5-2

INITIAL STRUCTURAL TOLERANCE ALLOCATIONS

ITEM \ ERROR SOURCE	G-RELEASE	LAUNCH HYSTERESIS	IPS MOTION-INDUCED VIBRATION	SECONDARY MIRROR MOTION INDUCED VIBRATION
PRIMARY MIRROR	0.0044μ RMS SURFACE	-	-	-
SECONDARY MIRROR	0.0016μ RMS SURFACE	-	-	-
INSTRUMENT FOCUS	8.0μ	8.0μ	8.0μ	8.0μ
SECONDARY DESPACE	0.85μ	0.85μ	0.85μ	0.35μ
SECONDARY DECENTER	12.5μ	12.5μ	12.5μ	12.5μ
SECONDARY TILT	2.93 ARC-SEC	2.93 ARC-SEC	2.93 ARC-SEC	2.93 ARC-SEC

the structure and validate the design are presented, followed by a discussion of the results and their relationship to the design requirements. Finally conclusions for future studies drawn from these recommendations are presented.

3.0 BASELINE DESIGN

The main purpose of the telescope structure is to house, point and meter the associated optical system. The design involves the use of a main ring surrounding the solid Cervit primary mirror from which all major components are referenced and attached. The ring is basically a built-up ring beam fabricated of aluminum plate to permit a low cost design. Figure 5-8 shows its main components.

3.1 Components Forward Of The Main Ring

Suspended from the forward end of the ring are the metering and the forward micrometeoroid shells.

The metering shell is made of graphite-epoxy for high stiffness and essentially zero thermal expansivity. To accommodate coefficient of expansion mismatch between the metering shell and the main ring, a set of radially compliant flexures are employed to connect them together.

The forward micrometeoroid shell isolates the metering tube from the thermal and micrometeoroid environments anticipated. Multilayer insulation is attached to its inner side for thermal control as well as light baffles for scattered light control. The shell length has been chosen to act as a sunshade, while the aperture doors at its front end are designed not only as aperture stops but also as part of the contamination control system.

A graphite-epoxy spider is suspended from an I-beam cross-section closeout ring at the forward end of the metering shell. The secondary mirror assembly is attached to the spider.

3.2 Components Aft Of The Main Rings

Three main structures are suspended from the aft end of the main ring; the aft truss, aft micrometeoroid shell, and focal plane support structure.

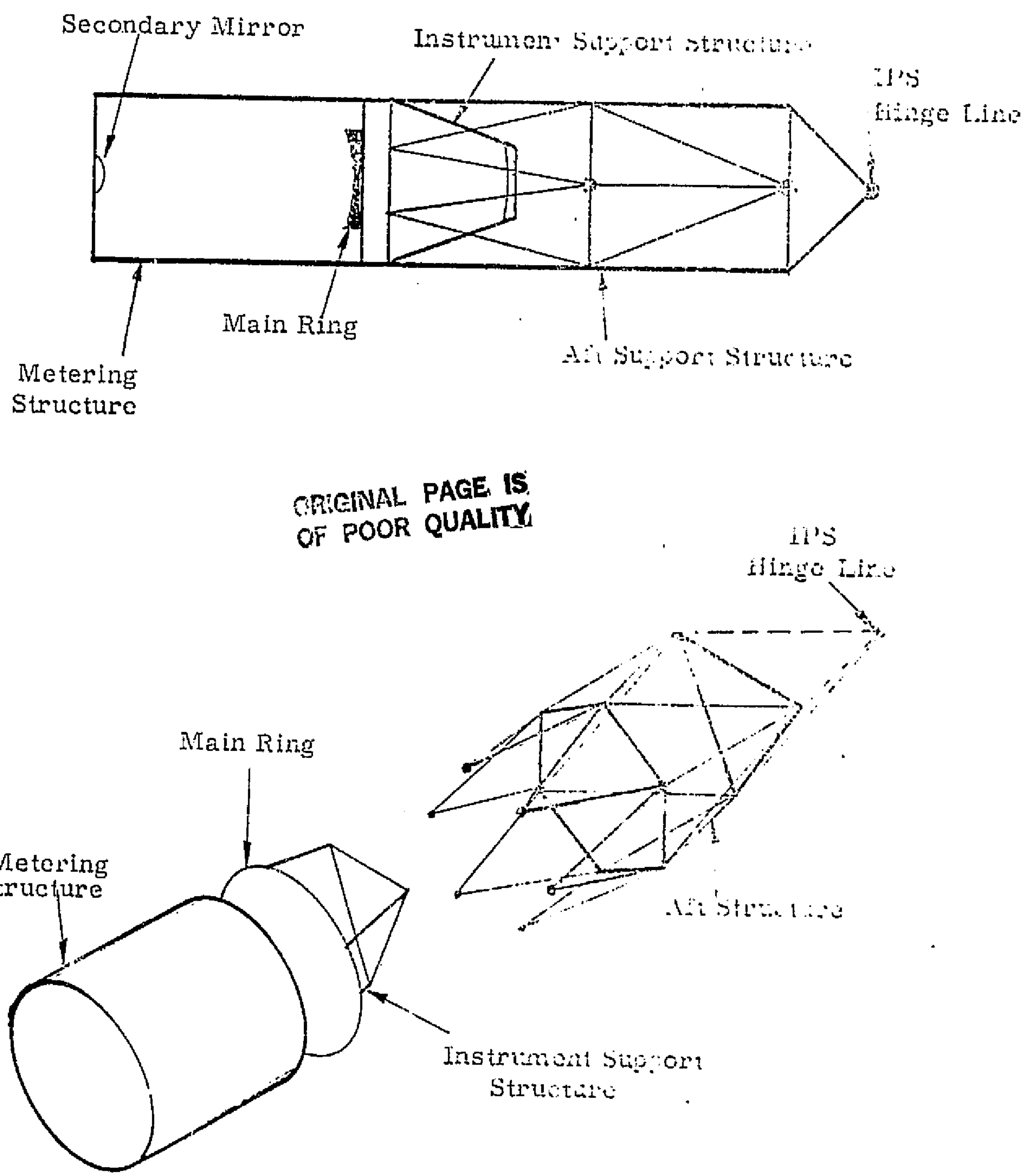


Figure 5-8 Exploded View - Starlab Structure

The aft truss is a two-bay structure whose main function is to connect the telescope to the IPS. Aluminum was selected, to minimize cost, although, a weight penalty was exacted in meeting the stiffness and strength requirements. However, sufficient weight margin existed in the system to permit selecting this design. The truss terminates in a triangular frame spanned by a bulkhead. This assembly permits attachment to the IPS at three points on its periphery, closes out the back of the system, and permits locations for attachment of IPS electronics. The IPS electronics are packaged as three modules mounted on the IPS bulkhead.

The aft micrometeoroid shell is similar to its forward counterpart in terms of function and design. To provide a pressure seal, it is attached to the aft bulkhead of the truss via a continuous flexural band.

The Focal Plane Bulkhead suspended from the aft end of the main ring is also an aluminum structure, whose main purpose is to mount and position the Science Instruments with respect to the focal plane. The structure, configured as a frustrum that is triangular in cross-section, was selected to permit the stationing of as many as three radial instruments. The structure is capped off by a bulkhead to locate the axial instrument and other smaller focal plane instruments on its aft end.

3.3 Components Mounted On Main Ring

The instruments are mounted to the main ring structure via predrilled bolt circles. Ball detents located on the structure assure these instruments are aligned to the bulkhead. To minimize operational sensitivity to tilt errors occurring in the alignment of the instruments, these detents are placed almost coincident to the optical axis.

Attached to the outer periphery of the main ring are the Star Tracker and the Payload Clamp Assembly (PCA) attachment fittings. The Star Tracker is attached here to minimize its relative motion with respect to the Primary Mirror. The attachment fitting locations were selected to assure that the resultant loads are transmitted through the center of gravity of the system.

3.4 Primary Mirror Assembly

A solid Cervit primary mirror is attached to the inner periphery of the ring, through a set of three tangential and three axial bars. Local fittings attached to the ring pick up these bars, to minimize the transmission of disturbances (alignment and thermal errors) to the mirror, which could result in figure errors. At the mirror end, pairs of bars (one axial and one tangential) are joined by fittings at the aft end of the mirror mount. The mount design employs a ball joint which is located at the 2/3 radial position to minimize the inertial response of the mirror. A three-point mirror mount having ball joints located at the neutral surface of the mirror, results in a kinematic mount that can withstand loads in any direction.

3.5 Light Baffle System

To provide stray light control, a baffle design has been incorporated into the system. Mechanically this involves the use of thin, fin baffles on the inside of the forward micrometeoroid shell and the metering shell, as well as a central cone baffle that goes through a central hole in the primary mirror and terminates on a bulkhead at the aft end of the main ring.

The baffle system also adds to the structural stiffness of the structures to which it is attached. The fin baffles provide local stiffening and buckling resistance for the shells. Similarly the cone baffle bulkhead provides radial stiffness for the main ring. These stiffening effects have not been included in the analysis to generate the telescope design; providing an element of conservation.

3.6 Contamination Control System

The contamination control system chosen for the telescope is based on the desire to maintain a slightly positive pressure within the telescope cavity at all times to prevent entry of contaminants that could degrade the optics. These problems arise only during the Shuttle launch and reentry portions of the mission when rapid pressure gradients occur in the Shuttle bay.

To obviate these problems the selected contamination control system employs vent valves that ensure the pressure inside the telescope is never more than a quarter psi greater than the Shuttle bay pressure. Nitrogen under pressure, and stored in a tank on the pallet, is used to purge the system and to maintain this slight overpressure, the entire system is sealed except for the vent valves. A compliant seal is used at the aft end of the micrometeoroid shell and seals are also used on the aperture doors to seal off that end of the telescope.

During reentry, a pressure sensing system increases the purge gas pressure such that it is always one-quarter psi greater than the Shuttle bay pressure, which is constantly increasing. Again the seals and vent valves are used to ensure that an overpressure (> ¼ psi) condition never exists.

The Contamination Control System concept further requires that during ground handling and prelaunch conditions a constant purge with nitrogen be continued.

3.7 Secondary Mirror Assembly

Early Starlab studies indicated that due to thermal response requirements, an active focus control would be necessary. Similarly, the extremely small despace allocations shown earlier, for mechanical disturbances, indicated that active correction also might be necessary. And further, image motion compensation requirements indicate that rotation of the secondary mirror around its neutral point is necessary. This translates into tilt and decenter motions of the secondary around its apex.

To accommodate these motions, a five-axis drive system is needed for the secondary mirror. For Starlab, a design has been extrapolated from previous design studies - Space Telescope (ST) and Synchronous Earth Orbiting Satellite (SEOS). A functional schematic is shown in Figure 5-9. It consists of three pairs of actuators located 120 degrees around the periphery of the mirror. By controlled expansion/contraction of each actuator, 5 degrees of freedom is possible.

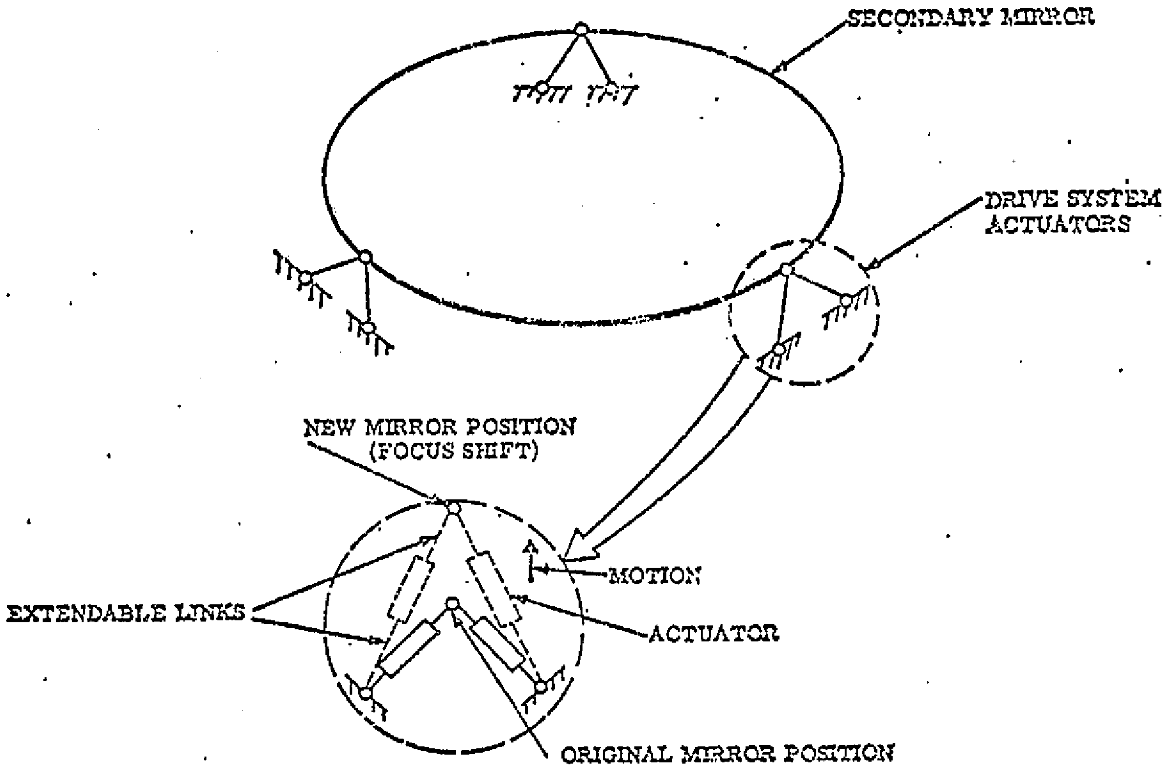


Figure 5-9 Secondary Mirror Drive System Schematic

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3.8 Mass Properties

The baseline design description is completed with a discussion of the system mass properties. Table 5-3 gives the system weight breakdown by major category. The total indicates that a considerable weight margin exists for the system, i.e., 19% even though the lightest weight design approaches were not employed. This indicates that more weight could be added to the system if further cost reductions are desired. On the other hand, it also indicates that if minimizing weight becomes an issue, further weight reductions are feasible. It should be pointed out that at this point, a 19% margin is about what should exist because of the ability of system weights to grow as they are further studied.

4.0 THERMAL SUBSYSTEM DESIGN

The optical performance of the Starlab Telescope is contingent on both the maintenance of high quality optical surfaces and the stable retention of the coordinate positions of the optical elements and the instrument sensors. Within the Starlab the latter is achieved by selecting optical and structural materials having minimum temperature sensitivities and by controlling the temperatures of these elements within narrow limits.

The Thermal Control Subsystem (TCS) must satisfy one key issue, namely, the Starlab facility must be ready to operate upon deployment. This overriding criterion severely restricts the TCS options and leads to a TCS configuration that maintains all critical optical elements at a constant temperature for the entire mission.

4.1 System Description

The proposed TCS design is based upon the selected use of heaters, insulation, and coatings to control the temperatures.. The baseline subsystem is composed of:

- Electrical heaters
- Heat control sensors
- Multilayer insulation
- Coatings with controlled α/ε surfaces
- Thermal electronic control unit.

TABLE 5-3. BASELINE DESIGN - WEIGHT SUMMARY

		Weight (Lbs)
Optics/Mounts		
Primary Mirror Assembly (Cervit)		700
Secondary Mirror Assembly (Cervit)		50
Instruments		992
Primary Structure		
Metering Shell Assembly (GR/Epoxy)		75
Aft Structure Assembly (Aluminum)		359
Main Ring (Aluminum)		114
Instrument Support Structure (Aluminum)		3[illegible]
Secondary Structure		
Aft Meteoroid Shell Assembly (Aluminum)		52
Forward Meteoroid Shell Assembly (Aluminum)		98
Aft Closeout Bulkhead (Aluminum)		70
Aperture Door Assembly (Aluminum)		80
Baffles (Aluminum)		10
Miscellaneous		
Star Tracker		40
Electronics		100
Multilayer Insulation		30
Thermal Control System		460
Miscellaneous Hardware		
	Total	3545
	Goal	4400
	Margin	855 (19%)

Since all critical optical surfaces are polished and Starlab elements are assembled, aligned, and tested at room temperature, the instrument precision will be preserved by maintaining the following elements at $70^{\circ} \pm 2^{\circ}$F ($\sim 21^{\circ} \pm \sim 1^{\circ}$C):

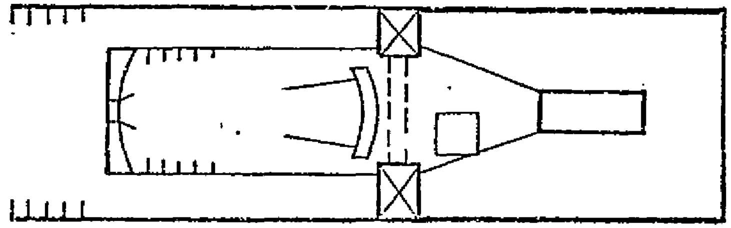
- Primary mirror
- Secondary mirror assembly
- Metering shell
- Instrument support truss
- Main ring.

The primary and secondary mirrors will be made of a low expansion glass such as ULE or Cervit. The metering shell and instrument support truss will be made of graphite-epoxy. The main ring will be aluminum.

The forward shroud exterior is covered with β-cloth (α/ε = 0.4/0.9) while the aft shroud exterior will be coated with a generic NASA coating as GSFC 101 or TiO_2 (α/ε = 0.2/0.9). The lower α/ε ratio in the aft section is needed to reduce solar input since the science instruments have a heat load that must be rejected. The higher β-cloth α/ε ratio is used to reduce heater power requirements in the forward section.

4.2 Thermal Model

The basic analytical thermal-math model is shown schematically in Figure 5-10. A reduced model, was used to obtain most of the results presented in this section. A reduced model is generally more cost-effective early in a design study where many design changes require frequent revisions. In order to complete the study on schedule, it was necessary to restrict design changes made after December 1, 1977. From a thermal standpoint this is essentially the final design arrived at in this study.



ELEMENTS	NO. OF NODES	ELEMENTS	NO. OF NODES
PRIMARY MIRROR	8	ELECTRONICS	1
PM BAFFLE	1	INSTRUMENT BAY SHELL (AFT)	32
SECONDARY MIRROR ASSEMBLY	1	AFT BULKHEAD	1
SM SUPPORTS	4	MAIN RING	4
METERING SHELL	12	SHUTTLE BAY	18
METEOROID SHELL (FWD)	36	EARTH T = -10	1
INSTRUMENT TRUSS	4	SPACE T = -441	1
INSTRUMENTS - RADIAL	1		
INSTRUMENTS - AXIAL	1	TOTAL	127
STAR SENSORS	1		

Figure 5-10 Basic Thermal Math Model

D. STARLAB TRACKING AND AQUISITION STUDY

Ball Aerospace Systems Division, July 1978

1.0 INTRODUCTION

This study was aimed primarily at the definition and design of an Image Motion Compensation (IMC) subsystem that would limit the focal plane errors to 0.02 arc-sec (RMS) for quiescent conditions and to less than 0.06 arc-sec for a dynamic situation.

The Starlab Facility is a rigidly attached structure to the Instrument Pointing System (IPS) and the system design approach to minimize the dynamic disturbances are in conflict with the requirements for maintaining a 0.02 arc-sec quiescent stability. An IMC with a wide bandwidth is necessary to attenuate the transient disturbances while a narrow bandwidth in the servo loop is required to minimize the noise contribution of the IMC subsystem.

BASD investigated two scenarios with the first introducing vernier thruster firings as the transient disturbance. The subsystem developed for this situation did not meet the Starlab quiescent noise stability requirement The vernier thruster firings were replaced by man-motion as the dynamic disturbing force. An IMC subsystem without the gyro's was designed that did meet both the transient and quiescent stability requirements.

Section three of the report deals with a detailed acquisition sequence for manual and automatic pointing of Starlab.

Section five presents the focus control and the recommended methods of implementation.

A Section and an Appendix are devoted to a treatise on Kalman filtering and the application to the Tracking and Acquisition Subsystem.

2.0 STARLAB LOCATION

The selection of a position for Starlab in the Orbiter bay was critical to the study since it determines the disturbance applied to the IPS and IMC. Starlab was placed in the Orbiter bay with the IPS gimbal axis at Station 1057. A representative 5-pallet payload was assumed which has a mass of 12,700 kg and a CG location at Station 950. The simulation was conducted with a pointing elevation of 30° from horizontal.

Figure 5-11 shows the location of Starlab in the Shuttle.

3.0 STARLAB STRUCTURAL MODEL

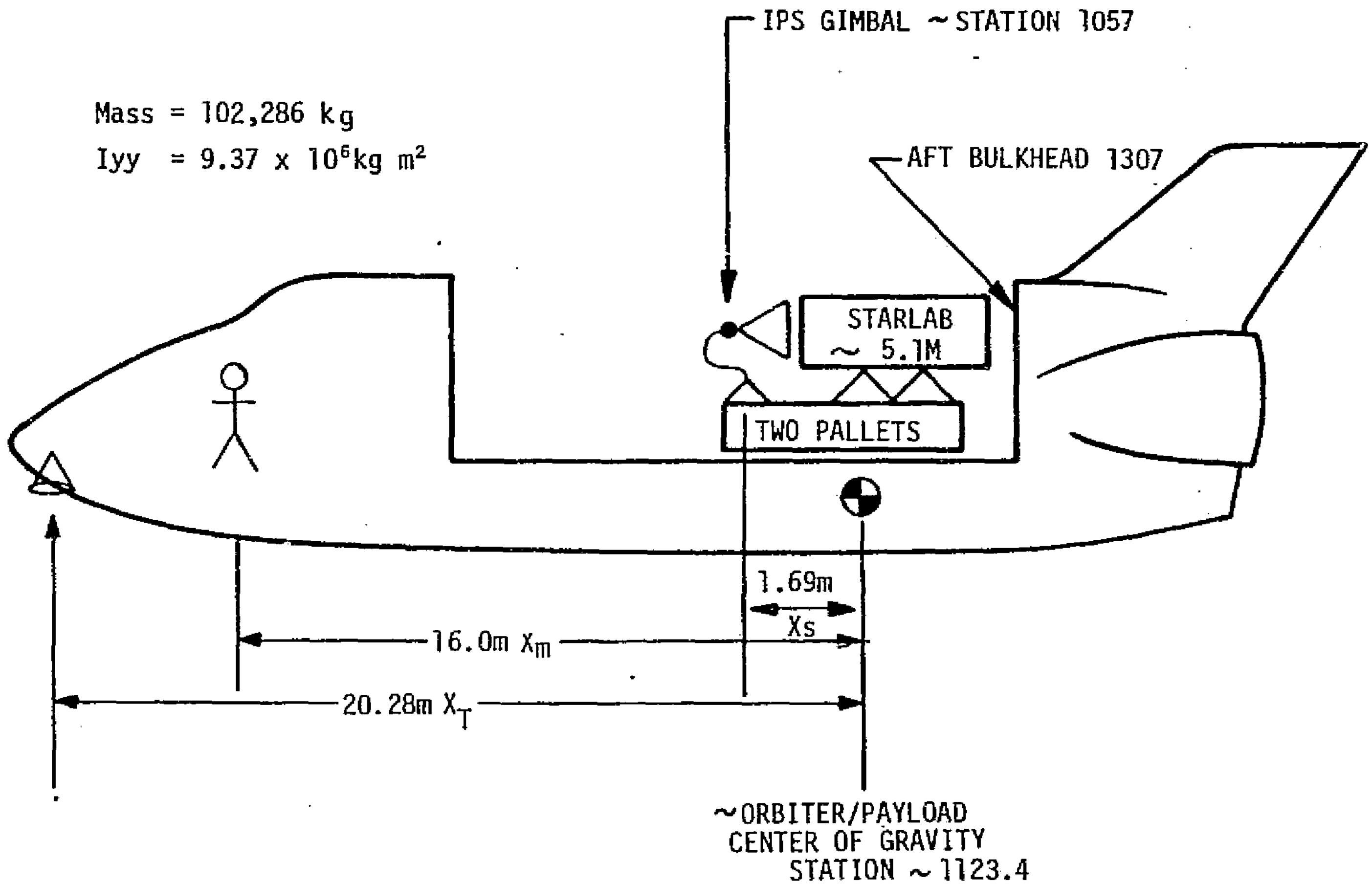
To determine what happens to pointing when a thruster disturbance is introduced into the Starlab/IPS system, a structural model of that system was needed to predict the position and the tipping of all of the optical elements. A finite element model with approximately 30 to 60 nodes is about the right level of complexity for the Starlab investigation.

During the course of the study three versions of the BASD in-house model, as well as the Perkin-Elmer model (see Figure 5-12) were analyzed. In the final dynamic analysis, the Perkin-Elmer model of Starlab was married to BASD models of the IPS and Spacelab pallet structures.

4.0 IMAGE MOTION COMPENSATION (IMC)

The stable pointing of Starlab at a celestial target is achieved by two independent servo loops. The only interactions between these two loops are inertial and structural. Figure 5-13 details the elements of the two control systems. The IPS loop operates at about 1 Hz and points Starlab with a stability of approximately 1-3 arc seconds. The bandwidth of this loop is generally limited by its interaction with structural flexibility of the telescope and the

LOCATION OF IPS GIMBAL AND DISTURBANCES WITH RESPECT TO ORBITER CENTER OF GRAVITY



- STARLAB (5.1M LONG) LOCATED IN AFTMOST POSITION IN ORBITER WITH IPS FORWARD
- ESTIMATED COMBINED ORBITER/PAYLOAD CENTER OF GRAVITY AT STATION 1123.4 (EMPTY ORBITER AT STATION 1148)
- IPS GIMBAL APPROXIMATELY 1.69 METERS FORWARD OF ORBITER/PAYLOAD CENTER OF GRAVITY

Figure 5-11

STARLAB FINITE ELEMENT MODEL (PERKIN-ELMER MODEL)

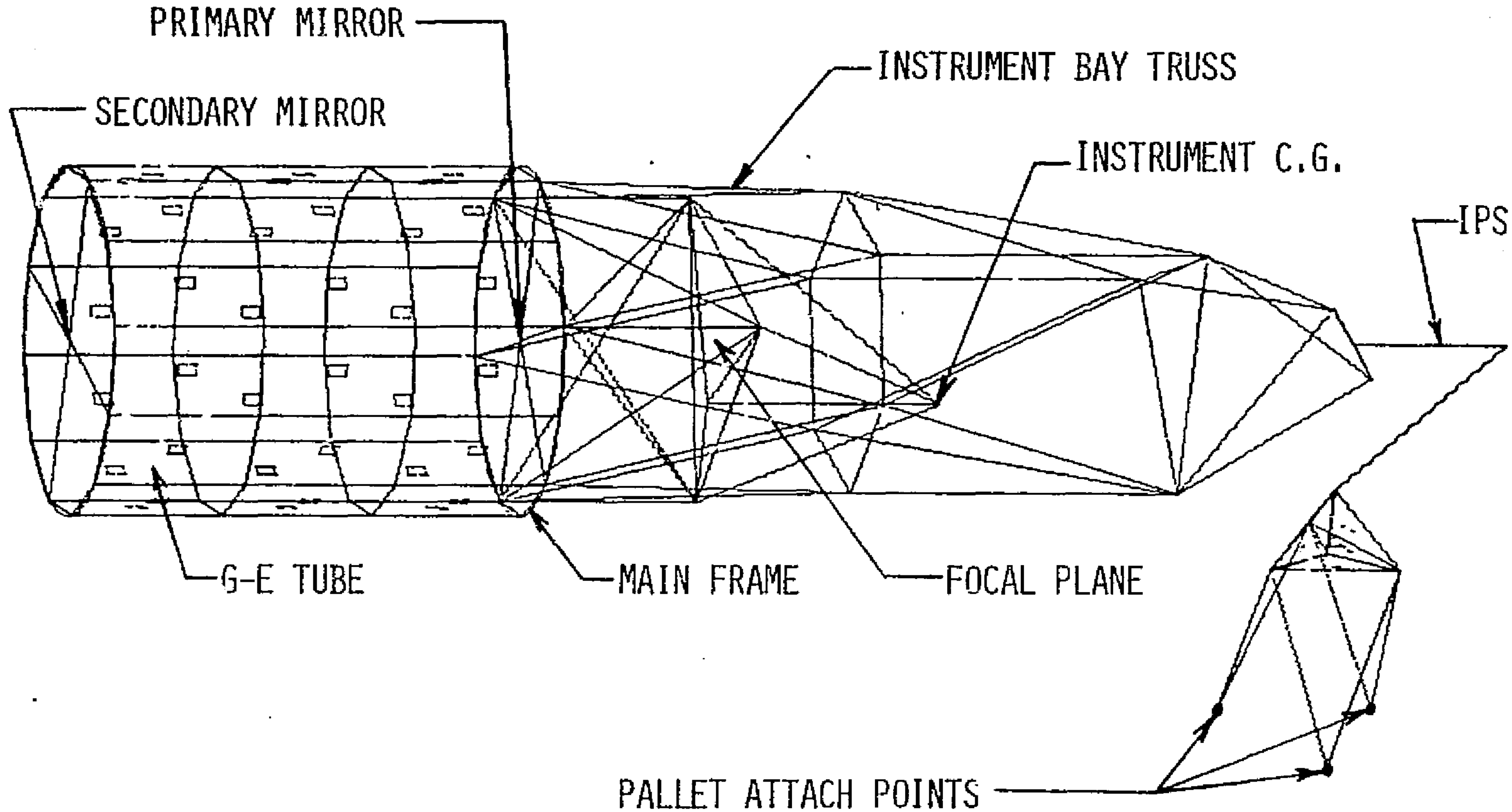


Figure 5-12

STARLAB-IPS POINTING CONTROL LOOPS

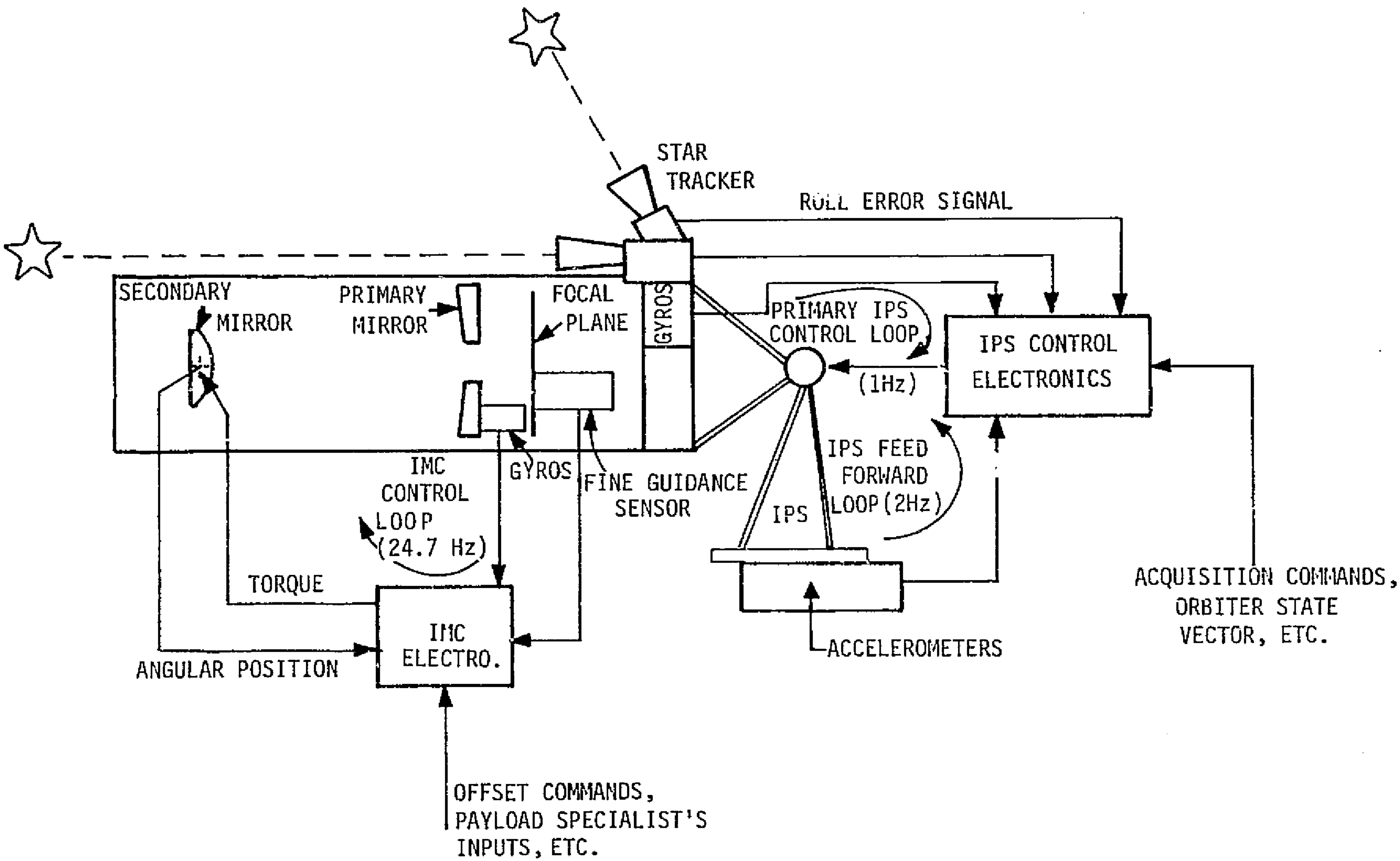


Figure 5-13

IPS itself. An instrument like Starlab, to fully utilize its optical capability, requires much greater stability than IPS can provide. This additional stability is achieved by an IMC servo. The basic idea is to detect motion in the focal plane with a fine guidance sensor (FGS) and use that information to articulate the secondary mirror in such a way as to limit the motion of the image in the focal plane.

4.1 IMC Sensors

Implementation of the IMC concept requires three sensors, namely a fine guidance sensor, a gyro, and a secondary mirror angle encoder. The locations of the fine guidance sensor and the encoder are determined by their function. The fine guidance sensor, since it must detect motion of stars in the focal plane, is itself located in the focal plane. The secondary mirror angle encoder measures the tilt of the secondary mirror relative to the local structure. This can be most easily accomplished at the secondary mirror. Placement of the gyro is less obvious. It only measures rotations at the point where it is attached. The Starlab structure is very stiff between the primary and secondary mirrors. It is much less rigid between the primary mirror and the IPS interface.

4.1.1 Fine Guidance Sensor

The fine guidance sensor is based on a modified BASD tracker design which uses an image dissector tube with a 10 x 10 mm format. This tracker works by counting photo events at four adjacent positions and computing differences. However, the present electronic design cannot meet the ten milli-second update interval requirement. To meet the required NEA and guide star probability requirement with ten milli-second update interval, it was necessary to increase the f number from 15 to 25. For the radial FGS, placement of the sensor in the .28 square degree field of view, which in this case is an annulus, is accomplished by offset-pointing and rolling with the IPS. In the case of the axial FGS in which the field of view is horseshoe shaped, the field is scanned both radially and azimuthally by articulating mirrors to place the guide star on the sensor. In both cases, the sensor is fixed in the focal plane.

4.1.2 Gyro

The requirements on the gyro are extreme. It must have both very high bandwidth and very low noise. As the analysis proceeded it became clear that a gyro with a bandwidth of about 600 radians per second would be required. Its noise contribution must be low enough that when combined with other noise sources, the .02 arc-sec quiescent requirement could still be met. Only one is included in this study; the Northrup Third Generation Gyro (TGG).

4.1.3 Secondary Mirror Angle Encoder

Because of the way the signals are combined, the requirements as to bandwidth and noise for the encoder are the same as they are for the gyro. The range of angles which must be measured is only a few arc minutes. The resolution, however, must be better than .03 arc-sec. No shaft angle encoder BASD research determined can meet these requirements. However, they are quite consistent with the characteristics of an autocollimator; the Micro Radian model MRA-108 met the requirements.

5.0 ACQUISITION

Acquisition is comprised of two sequential steps, IPS and Starlab. First, the IPS must acquire its guide star and establish its pointing to approximately 1 arc-sec stability. Then Starlab can research for, locate its guide star and activate the IMC circuitry. An expanded and detailed acquisition sequence is presented in paragraph 3.0 of the Electronics/Command and Data Handling subsystem Study, section E of V, phase B studies.

Initially, the FGS was required to track 13th magnitude stars in order to achieve a .9 acquisition probability. However, improvements in the FGS and the focal plane arrangement developed in the Starlab Instrument Design Concept Study increased the FGS field of view. These changes provide .95 acquisition probability while tracking 12th magnitude stars at the galactic pole. Both IPS and Starlab must acquire in order to make an observation, thus the probability of making an observation is thus approximately the product of the probability of an IPS acquisition and FGS acquisition. Since both the IPS and find guidance sensor have individual probabilities of having acceptable guide start in their fields of view of at least .95, the combined probability and thus the probability of making an observation exceeds .9.

In the section on acquisition, a step-by-step procedure for acquiring the target is described in detail. This procedure may be implemented either automatically under computer control or manually by the payload specialist. An external view-finder camera is provided to verify that acquisition has been achieved.

6.0 ROLL AND LINE OF SIGHT STABILITY

The line of sight stability requirement has been generally accepted as .02 arc-sec RMS. This is one-tenth of the optical resolution over the corrected science field-of-view. At the study kick-off meeting, however, it was agreed that "RMS" is not the optimum way in which to specify a stability requirement where the noise source is large, short impulses separated by long time intervals. It was therefore decided that BASD should use a .06 arc-sec peak for the stability requirement under the influence of a worst-case thruster firing and .02 arc-sec RMS for quiescent conditions where sensor noise dominates.

Two points are made concerning roll stability. First, the IMC proposed in this study cannot compensate for a roll distrubance. Second, the IPS specifcations for roll stability (10 arc-sec) is just adequate to meet the Starlab stability requirement. This is seen in the following calculation. Peak acceptable linear motion in the focal plane consistent with .06 arc-sec. line of sight error is .06 times the focal length and computes to be 4.36 microns. The roll angle which will produce this motion os 4.36×10^{-3} mm divided by the linear radius of the field of view (90 mm) or 10.0 arc-sec.

Also, since the fine guidance sensor may be at the edge of the field-of-view a roll motion will be interpreted by the IMC servo as a tip about the line of sight which it will attempt to correct. These motions will, in the worst case still meet the .06 arc-sec peak requirement.

6.1 Kalman Filter

The reason for building a Kalman filter into the IMC servo is to obtain the best possible estimate of certain state variables and form an error signal from them. One of the benefits of this technique is that simulations of the system need not be constructed and exercised to see how well it operates.

The entire analysis consisted of modeling the system and its attendant noise sources, computing the state transition and various covariance matrices, and then propagating the state covariance and Kalman gain matrices forward in time. An estimate was made of the features required of a computer which would solve the equations in real time. The requirements are very severe and it will probably be necessary to simplify the filter to achieve a practical flight model.

7.0 FOCUS REQUIREMENTS

The tasks and requirements for focus control were as follows:

- Decide whether to move the primary or secondary mirror in order to bring the telescope into focus.
- Identify a concept to detect an out of focus condition.
- Develop a conceptual, mechanical design for moving the appropriate mirror to bring the telescope into focus.
- Determine whether there is any detrimental interaction between focusing controls and the IMC servo.

In the focus study it was assumed that, due to launch loads and g release, the primary and secondary mirror separation might deviate as much as $\pm$ .5mm, from the nominal separation. The tolerance on this separation, for maintaining optimum focus, is 2.4×10^{-3} mm. Thus, a focus step size of 10^{-3} mm was deemed adequate.

8.0 SPACELAB AND SHUTTLE INTERFACES

Starlab Acquisition and IMC subsystems interface with Spacelab and Shuttle with several input and output ports. The IPS acquisition interfaces for Starlab are the normal IPS-to-Spacelab interfaces, using the Subsystems Data Bus, Subsystems Computer, and Mass Memory Unit. The FGS interfaces with the Spacelab Experiment Data Bus. The Slit Camera and External Television camera interface with the Orbiter Closed Circuit Television System.

Starlab operations are performed by the Experiment Computer software. The IPS subprograms would be correlated with Starlab programs, which would provide for instrument selection for each target and such instrument operations as filter selection, integration time, gain settings, etc. The experiment programs can receive information from the IPS subprograms such as IPS commanded attitude and GMT. The Starlab operations can also be manual or semi-automatic.

Mission operations subprograms currently planned permit the IPS to point to a number of target stars in a specified sequence, dwelling on each one for a specified length of time. The IPS software can also compute times of actual and effective sunrise, sunset, target rise, and target set. FGS star positions would be programmed into these subprograms for IPS operations during normal acquisition sequences. The IPS operations can be manual or semi-automatic (with automatic programs interruptible by the ground or crew)

8.2 Slit Camera and External Television Camera Interfaces

The Slit Camera and External Television camera can use two of the three payload video channels available in the Orbiter CCTV video switching network.

E. ELECTRONICS/COMMAND AND DATA HANDLING SUBSYSTEM DEFINITION DESIGN STUDY

1.0 INTRODUCTION

The purpose of this study was to define the electrical and operational requirements of the STARLAB facility with a "strawman" payload of science instruments and design a Shuttle/Spacelab pallet-only configuration compatible electronics subsystem to meet these requirements. Shuttle/Spacelab capabilities discussed in this report are those having the most impact on STARLAB configuration or operations. These areas include the Instrument Pointing System (IPS), Spacelab command and data management subsystem capabilities, experiment computer operating system (ECOS) software provisions, shuttle manual display and control features, power control and management subsystem, and the Orbiter CCTV system capabilities.

2.1 Facility Requirements

A review of the Telescope Facility requirements is presented with associated assumptions for command, control, and monitoring functions. A preliminary estimate of power and duty cycle is made, See Table 5-4.

The power subsystem estimates are based on the use of the full power available at the gimbal interfaces, i.e., 700 watts.

2.2 Instrument Requirements

Power, control, status monitoring and science data requirements have been determined for a representative group of eight instruments. A section is

TABLE 5-4

FACILITY POWER REQUIREMENTS

SUBSYSTEM	POWER (WATTS) AND DUTY CYCLE %				
	MIN	NOM	STNDBY	MAX	AVG
TELESCOPE DOORS		0 99%		15 1%	0.2
PRESSURE SYSTEM		0 99%		5 1%	--
THERMAL SYSTEM FORWARD BAY	187 50%			292 50%	240
INSTRUMENT SELECTOR		0 90%		15 10%	1.5
AXIAL FGS		12 95%		22 5%	12.5
RADIAL FGS		12 100%			12
IMC ELECTRONICS		175 99%		185 1%	175
AQUISITION CAMERA		40 100%			40
SLIT CAMERA			3 40%	32 60%	20
COMMAND AND DATA SUBSYSTEM		55 100%			55
POWER SUBSYSTEM		141 90%		151 10%	142

devoted to a description of each instrument coupled with the assumptions made for the purpose of this study. The instrument power requirements are shown in TABLE 5-5. TABLE 5-6 presents the predicted Science Instrument (SI) data rates.

2.3 Power Problem

Required power vs. available power is a problem. This is explored further in Section VI of this summary document.

3.0 OPERATIONAL CONSIDERATIONS

From inception, Starlab has been conceived as a predominately manually operated system. Operation from either the payload specialist's station on the Orbiter aft flight deck, or from the payload operation's control center on the ground, is a system requirement. A primarily manually run system is attractive from the cost standpoint. It avoids a more costly automated system by taking advantage of the Space Shuttle's ability to fly experienced scientist operators. In addition, experience with groundbased telescopes has shown that human judgment is indispensable in pointing operations involving faint, unfamiliar and hard-to-locate objects. Thus, although the facility may be operated by sequences of stored commands, the decision capability required will be supplied by a human operator. The sequence proposed emphasize the manual operation from the payload specialist's station.

3.1 IPS Deployment And Alignment

On arrival in Orbit, the IPS (and telescope) must be deployed from its launch configuration and the IPS control system initialized. The latter step requires positioning of the Orbiter in a suitable attitude. When these steps are successfully completed, the IPS is able to orient the axis of the IPS tracker (boresight sensor of the optical sensor package) within 2 arc seconds of a target whose coordinates are available.

To complete the preliminary operations, the alignment of the IPS tracker axis with the telescope axis for both axial and radial instruments must be determined. These measurements determine a set of "corrections" which, when applied to IPS pointing coordinates, enable the IPS to position a guide target on the radial or axial FGS. Since the physical alignment of telescope

TABLE 5-5

INSTRUMENT POWER ESTIMATE

INSTRUMENT	POWER, WATTS & DUTY CYCLE %				
	MIN	NOM	STDBY	MAX	AVG
DIRECT IMAGING CAMERA	12 15%	30 40%	20 40%	60 5%	25
PLANETARY CAMERA	23 10%	108 60%	35 20%	142 10%	93
FAR ULTRAVIOLET SPECTROGRAPH	63 20%	110 30%	33 30%	156 20%	87
PRECISELY CALIBRATED SPECTRO/PHOTOMETER	21 10%	35 60%	34 20%	63 10%	35
FOURIER TRANSFORM SPECTROGRAPH	12 5%	107 40%	12 15%	138 40%	125
ECHELLE SPECTROGRAPH	30 10%	81 35%	30 35%	106 20%	63
FABRY-PEROT SPECTROGRAPH	21 10%	53 70%	21 10%	84 10%	49
FAINT OBJECT SPECTROGRAPH	58 10%	110 50%	84 35%	188 5%	99

TABLE 5-6

INSTRUMENT SCIENCE DATA CHARACTERISTICS

INSTRUMENT	IMAGE FORMAT AND DATA RATES					REMARKS
	PIXEL/IMAGE	BITS/PIXEL	BITS/IMAGE	SEC./IMAGE	AVG. RATE	
DIRECT IMAGING CAMERA		DNA - FILM CAMERA				
PLANETARY CAMERA	800 x 800	8	5.12×10^6	0.1 Sec.	6.92 MBPS	800 x 800 CCD Array (A-D Conversion rate limited)
FAR ULTRAVIOLET SPECTROGRAPH	2048 x 128 x 5	7	9.18×10^6	60 Sec.	153 KBPS	5 Microchannel Array detectors 2045 x 128 pixels
PRECISELY CALIBRATED SPECTRO/PHOTOMETER	1024 x 2 channels	8	65.5×10^3	60 Sec.	1.09 KBPS	3 Microchannel Arrays, 1 CCD, Dual Channel
FOURIER TRANSFORM SPECTROGRAPH	2^{13} Samples/ Scan	12	98.3×10^3 Bits/Scan	1 Sec.	98.3 KBPS	Photomultiplier Detector
ECHELLE SPECTROGRAPH	2000 pxls/ line	7	14.0×10^3 Bits/line	60 Sec.	1.4 KBPS	SEC. Vidicon Detector
FABRY-PEROT SPECTROGRAPH	TBD	TBD	TBD	300 Sec.	Low	Photomultiplier Detector
FAINT OBJECT SPECTROGRAPH	2048 x 64	8	1.05×10^6	60 Sec.	17.5 KBPS	Multiple Anode Microchannel Array

and optical sensor package tracker is expected to remain constant within about $\pm$ 2 arc seconds, alignment measurement will be needed only infrequenly.

3.2 Acquisition Of Targets

Acquisition of a target for scientific observation requires pointing the telescope so as to position a guide star in the field-of-view of a FGS. When this is accomplished, the IMC system can track the target, compensating for disturbances which the IPS loops cannot handle. Two methods are available to acquire a guide target. In the first approach, acquisition is accomplished manually while the operator observes the target display provided by the finder telescope (acquisition camera). The second method relies on the accuracy of the IPS to position the guide target on the FGS directly, once target coordinates and alignment corrections are known.

Target acquisition for narrow-field axial instruments requires, in general, further steps before observation can start. Once the telescope is pointed and the guide star is being tracked, the target is positioned on the instrument entrance slit by means of the slit jaw camera which displays the slit on the TV monitor, in the payload specialist's station.

3.3 Other Operational Concepts

Other STARLAB operations with possible impact on C&DHS capabilities include alternation of observations, multiple orbit exposures and coordination of observations with observations made elsewhere. Alternating exposures with the radial instruments to obtain images of a target at various wavelengths will be a usual mode of operation. Alternate measurements with a radial and axial instrument will also be possible, but is not expected to be a frequently used mode. Multiple orbit exposures of faint objects, perhaps alternating instruments on day and night half-orbits, may also be expected.

Sequential use of the radial instrument requires that two, perhaps three, instruments be powered simultaneously. To conserve power the waiting instrument should be in a standby mode which uses the smallest amount of power possible to keep the instrument ready for use. For multiple orbit exposures, the instrument with a partially formed imaged must remain powered while awaiting its next exposure period. Instrument design should make this power as low as possible.

Coordination of data with data taken simultaneously from ground-based facilities is a desirable capability. To enable such coordination, all imaging data must be tagged with the absolute time it was taken. The SPACELAB provided GMT should be used for this purpose. For long exposures, both start and stop times should be identified. Time of observation will also be valuable in observation of objects with periodic or variable characteristics.

4.0 SHUTTLE/SPACELAB INTERFACES

The Shuttle and Spacelab resources, capabilities, and interfaces are discussed and the restrictions noted. The following areas are examined in detail.

- Space craft configuration
- Instrument pointing system
- Telemetry links
- Shuttle/Spacelab Command and Data Management System
- Data Display Unit
- Orbiter CCTV System

4.1 Spacecraft Configuration

Starlab physical dimensions require that it be flown with the Orbiter in pallet-only configuration. No Spacelab module will be flown; Spacelab electronics will be housed in the igloo. Only one data display unit (DDU) and keyboard will be available, located on the Orbiter aft flight deck in the payload specialist's station. Two TV monitors, part of the CCTV system, are located on the AFD and a third TV monitor, will be located in the payload specialist's station. The CCTV system, in pallet-only configuration, requires Video switching of acquisition and slit-cameras to be done in Starlab hardware. The high rate data recorder will not be flown in pallet-only configuration.

4.2 Instrument Pointing System (IPS)

The IPS provides the means to point the Starlab telescope. Its operational, electrical and mechanical features determine Starlab configuration to a large extent. The electrical interface at the IPS gimbals imposes a major constraint on Starlab functions. Table 5-7 lists the signals available. Functions listed in Table 5-7 are included only to define electrical characteristics; the lines can be used for other suitable functions. All power listed in Table 5-7 is available for payload use; none need be budgeted for IPS functions, including the optical sensor package.

TABLE 5-7

ELECTRICAL INTERFACE AT IPS GIMBALS

POWER:	3 Primary dc busses
	200 watts continuous
	350 watts peak for 15 minutes each
	1 experiment essential power bus
	100 watts continuous
	1 dual redundant emergency power bus
	50 watts continuous
SIGNALS:	Wiring for 3 experiment RAUs
	Wiring for 3 high-rate MUX inputs to 16 MBPS. 6 twisted, shielded pair @ 125 ohms.
	Wiring for 1 CCTV channel and sync. 2 twisted, shielded pairs @ 75 ohms.
	Wiring for 1 analog channel, to 4.5 MHz, 1 twisted, shielded pair @ 75 ohms.
	10 pairs flat conductor shielded, general use.

4.3 Telemetry Links

Telemetry functions provided in Orbiter avionics are given a brief overview to emphasize those features directly impacting Starlab functions. Two telemetry paths from Orbiter to ground installations are available: the Space Tracking and Data Network (STDN), a direct S-Band link to various ground stations and the Tracking and Data Relay Satellite System (TDRSS) KU-band link with two relay satellites and one ground station.

4.4 Shuttle/Spacelab Command And Data Management Subsystem

A section on Command and Data Management Subsystem (CDMS) hardware and software emphasizes CDMS system features most influencing the Starlab C&DHS design. The topics treated include RAU and high-rate multiplexer (HRM) aspects, on-board data storage for use during periods without telemetry coverage and ECOS functions.

4.5 Data Display Unit and Keyboard

4.5.1 Keyboard

The keyboard and associated display unit provide operator interface with Spacelab units, experiment computer and associated hardware and payload experiments. In the pallet-only configuration, one data display unit is provided on the Orbiter aft flight deck. The data display unit panel features a 12-inch diagonal tri-color TV monitor screen. Some of the more important display features include:

- Tri-color: red, yellow, green
- Vecor capability: 1024 lengths, 4096 angles
- 128 alphanumeric symbols
- 2 character sizes:
- Screen capacity: 22 lines of 47 characters

Beyond those display attributes listed above, display capabilities and details are determined by ECOS software. These features may affect the ease with which Starlab may be operated and influence the C & DHS architecture. In the typical Spacelab operation situation, commands and data for more than one system experiment (e.g., IPS, Starlab Telescope, Selected Instrument) must be handled simultaneously in real-time. Since the keyboard is general-purpose, keystrokes must control different experiments at different times. To achieve this, data displays are formatted in pages. Each page is assigned or allocated to an ECOS applications program or a DEP.

4.6 Orbiter CCTV System

Orbiter avionics system provides a closed-circuit television (CCTV) capability intended for visual monitoring of cargo bay and cabin area activities. This system is under consideration for use in Spacelab operation in conjunction with the acquisition and slit jaw camera units. Experiment-originated composite video signals are routed via a video switching network to onboard TV monitors, and to the FM signal processor for subsequent transmission to ground via the S-Band link. Both video switch and monitors are located on the aft flight deck of the Orbiter.

5.0 MECHANIZATION OPTIONS

Telescope functions are not expected to change with mission and can, therefore, be implemented with minimum regard for flexibility. Instrument complement, and therefore functional requirements, however, may change from mission-to-mission. A Starlab architecture, capable of accommodation of changing instrument requirements with minimal impact on facility functions is a desirable goal. This can be achieved by keeping telescope and instrument functions separated. The only interconnection between instrument and facility functions is that provided for the telescope engineering data so that it may be included with the down-link science data and can be implemented in either hardware or software. Any processing capability required for telescope functions would accordingly be supplied by a DEP dedicated to those functions (telescope DEP). Similarly, instruments would also have a dedicated processing capability.

Mechanization options are discussed in detail and include Tradeoffs for the following:

- Mechanize in hardware

- Mechanize in telescope DEP software
- Mechanize in payload DEP software
- Mechanize in instrument DEP software
- Mechanize in instrument hardware.

As ground rules for trade-off studies, it was assumed that the full capacity of the three experiment RAUs on the IPS integration ring may be used for Starlab functions. A complement of four instruments, the Direct Imaging Camera, Far Ultraviolet Spectrograph, Precisely Calibrated Spectrophotometer and the Planetary Camera, was also assumed. Spacelab equipments and capabilities in the pallet-only configuration will be used, as this is the more conservative case. A typical operational time line requires observations with each instrument, in turn, for one-half hour over the duration of the mission. The operating instrument will be fully powered and the waiting instrument will be in a standby mode to conserve power.

5.1 Mechanization Summary

Table 5-8 is an implementation listing for all of the STARLAB C&DHS functions.

6.0 RECOMMENDED C & DH SUBSYSTEM

A configuration for the STARLAB C&DH is shown in Figure 5-14. It comprises the telescope processor, digital multiplexer, analog multiplexer, the A to D converter, CCTV Video switch, and an optional Science data switch. The power subsystem is presented in Figure 5-15.

TABLE 5-8

STARLAB C&DHS IMPLEMENTATION SUMMARY

FUNCTION	IMPLEMENTATION CHOICE
Telescope Analog Multiplexing	Hardware
Telescope A to D Conversion	Hardware
Telescope Engineering Data Formatting	Telescope DEP Software
Telescope Engineering Data Display Formatting	Spacelab Experiment Computer
Telescope Status Display	Spacelab DDU
Telescope Manual Control (Orbiter Real-Time Commands)	Spacelab DDU
Telescope Stored Commands	Telescope DEP Software
Telescope Command Interlock	Telescope DEP Software
Telescope Ground Real-Time Control	Orbiter Up-link/EC Software/ Telescope DEP Software
Telescope Distribution and Timing	Telescope DEP Software
Telescope Acquisition and Data Field Display	Orbiter CCTV System and Monitor
Telescope CCTV Input Select Switch	Telescope Hardware
Instrument Analog Multiplexing	Instrument Hardware
Instrument A to D Conversion	Instrument Hardware
Instrument Engineering Data Multiplexing	Instrument Hardware
Instrument Engineering Data Formatting	Instrument DEP Software
Instrument Engineering Data Display Formatting	Spacelab Experiment Computer
Instrument Status Display	Spacelab DDU

TABLE 5-8 (Cont'd)

Instrument Manual Control (Orbiter Real-Time Commands	Spacelab DDU
Instrument Stored Commands	Instrument DEP Software
Instrument Command Interlock	Instrument DEP Software
Instrument Ground Real-Time Control	Orbiter Up-Link/EC Software/ Instrument DEP Software
Instrument Command Distribution and Timing	Instrument DEP Software
Instrument Science Data Multiplexing	Telescope Hardware
Instrument Science Data Processing	Instrument DEP Software
Instrument Science Data Formatting	Instrument DEP Software
Instrument Science Data Storage	Spacelab Payload Recorder
Instrument Science Data Display	Instrument Hardware/Software and Orbiter CCTV System
Power Subsystem	Hardware

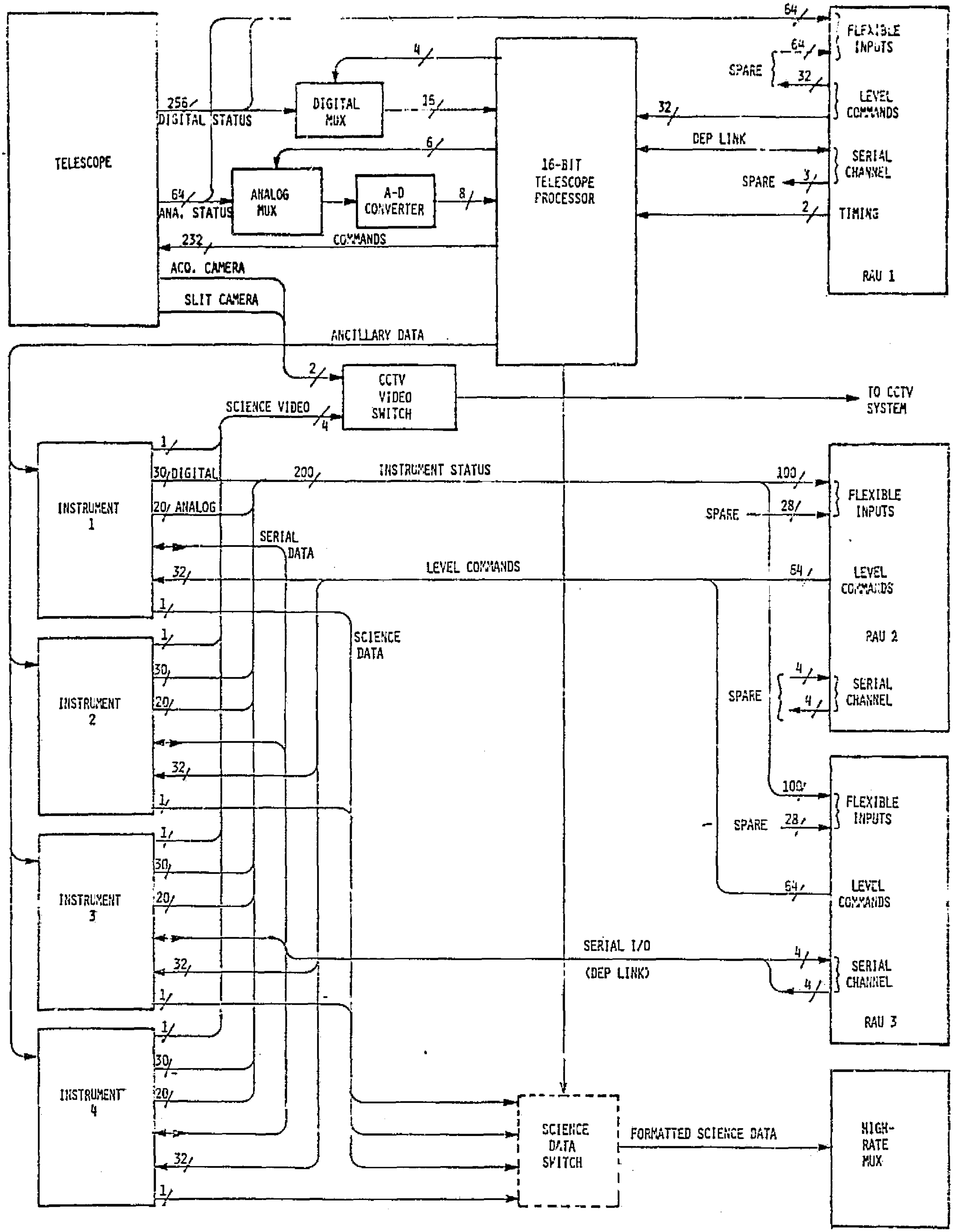


Figure 5-14 STARLAB BLOCK DIAGRAM

ORIGINAL PAGE IS OF POOR QUALITY

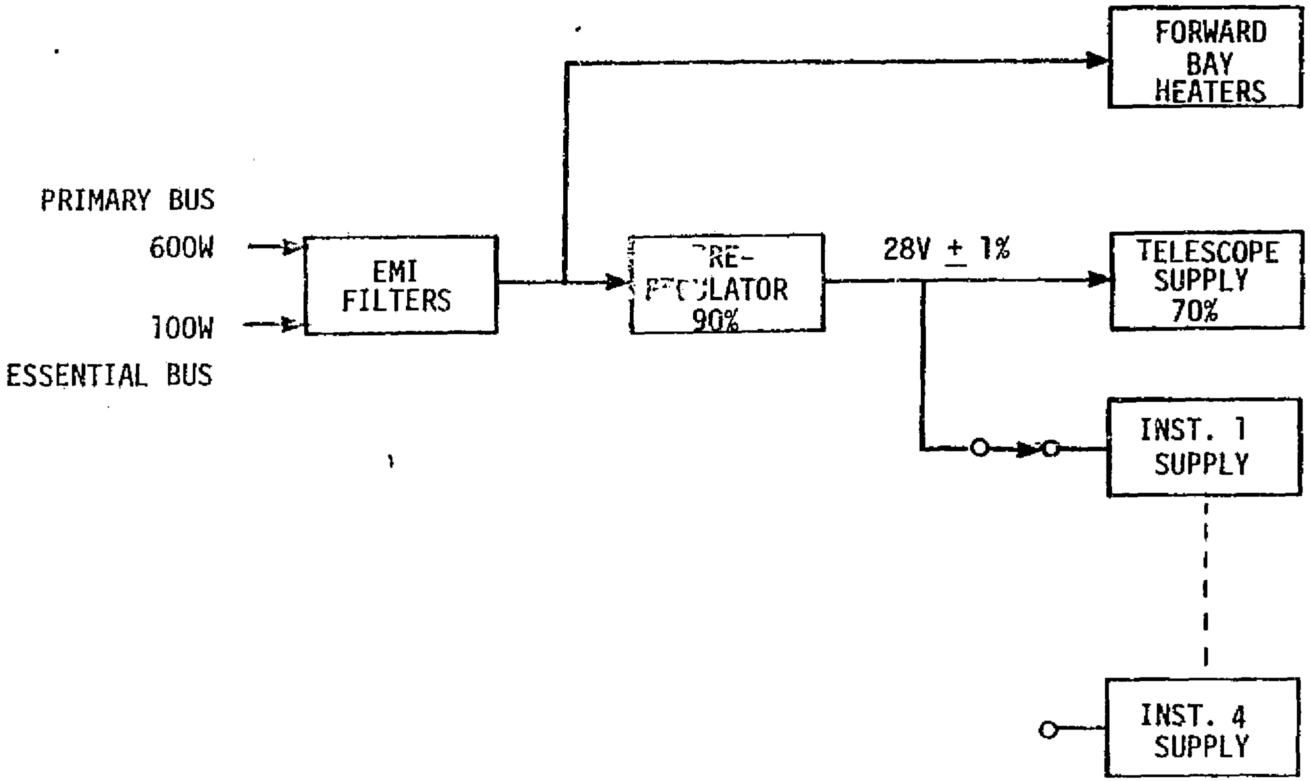


FIGURE 5-15 POWER SUBSYSTEM BLOCK DIAGRAM

VI. TECHNICAL CONCLUSIONS

The conclusions reached in each of the five Phase B subsystem design studies are presented in summary form. The Design Studies are:

- OPTICAL SUBSYSTEM DESIGN
- INSTRUMENT DESIGN CONCEPT
- STRUCTURAL/THERMAL SUBSYSTEMS DESIGN
- TRACKING AND ACQUISITION DESIGN
- COMMAND AND DATA HANDLING SUBSYSTEM

There are some additional system considerations worthy of separate mention and include:

- Contamination Considerations
- Stability and Image Motion Compensation
- Facility Mechanical Design Trade-offs.

OPTICAL SUBSYSTEM DESIGN

Perkin-Elmer March 1978

The optical design for Starlab completed in this study nominally provides essentially perfect performance over the system field-of-view. For axially located instruments, the design has no aberrations. For wide field instruments, such as the wide field camera, the corrector produces imagery that, after camera optical correction, is essentially perfect to the intended detectors. Off-axis sensors not having precorrected imagery must cope with the astigmatism and field curvature of the Ritchey-Chretien configuration. The astigmatism and field curvature, however, are not complicated by uncorrected higher order aberrations. As a result they can be corrected easily by a fairly simple means within the off-axis instrument itself. This procedure is quite common.

The more important conclusions of this optical design study are presented:

- Optical design 1 meter, f/15 Ritchey-Chretien
- Gascoigne corrector design has been improved
- Corrector may be used with or without faceplate
- Optical tolerances imply high quality but are reasonable
- Focus control recommended for primary mirror thermal sensitivity
- Seal and purge system is required to maintain system optical quality
- P&T interactions are nill if secondary is rotated about common point with final optical design
- Baffle design shows 36% obscuration, 40% specifiable
- System uses proven configurations throughout

Instrument Design Concept Study

Ball Aerospace Systems Division April 1978

This report consists of two major parts. The first describes the arrangement of scientific instruments and support equipment in the focal plane of the STARLAB telescope. The second part describes design concepts of these instruments.

The most important factor in the evolution of the focal-plane arrangement was the need to increase the speed of the internal image-motion compensation with the Instrument Pointing Subsystem (IPS), developed by the European Space Agency (ESA). A second factor was the desire to increase the number of radial instruments from one to three.

- The basic focal plane structure is a triangular box mounted to the telescope main ring which serves as the mounting base for all focal-plane subsystems and scientific instruments.
- Each side of the triangle has a removeable panel on which a radial scientific instrument can be mounted.
- The back surface of the focal-plane structure carries an alignment reference point and provides mounting space for the axial scientific instrument.
- The back plate carries, as permanent facility instruments, a slit camera and a Planetary Imaging Camera (PIC).
- The back plate also contains a Fine-guidance Sensor (FGS) to stabilize the telescope image presented to the axial instrument and the PIC.
- The three radial instruments share a single radial FGS.

- To create space for the additional radial instruments, the Phase A viewfinder camera is removed from the focal plane and replaced by a fixed, external television camera.

The four focal plane subsystem elements of STARLAB that are required to successfully operate the facility in orbit are:

- Axial and radial fine guidance sensors
- Instrument selector
- Focus sensor
- Acquisition Camera

STRUCTURAL/THERMAL SUBSYSTEMS DEFINITION DESIGN STUDY

Perkin-Elmer March 1978

The Starlab Phase B Structural/Thermal Design Definition Study used as its starting point and built upon the previous Phase A studies. Principal guidelines were to provide and analyze a cost-effective, low-risk structural and thermal design for Starlab using proven techniques and components. The designs were to be developed to a Phase B level based on Phase A inputs.

STARLAB STRUCTURAL SUMMARY

- Three Major Structural Subsystems Mounted to Main Ring
  - (a) Graphite-Epoxy Shell Supports Secondary Mirror
  - (b) Truss Aft Section to Connect to IPS - Instrument Accessibility Maintained
  - (c) Separate Instrument Foundation Truss, Carries Instrument Weight
- IPS Structural Interface Studies
- Structural Math Model Generated
  - (a) First Order Design and Analysis Complete
  - (b) NASTRAN Model Completed and Supplied
- Telescope is Rigid to the Optical Tolerance Level in Operation
  - (a) 25 Hz Structure Throughout
  - (b) Launch Effects Have Been Considered
  - (c) Pointing & Tracking Interactions Have Been Minimized
- Low Cost/Low Risk/Proven Configurations Considered Throughout

STARLAB THERMAL SUMMARY

- Key Overall Requirement - "Operate Upon Deployment"
- Used Conservative Operating Scenarios-GSFC-Supplied

- Used Baseline Science Instrument Requirements
- Instrument Area is the Most Thermally Variable
- Developed Flexible Thermal Math Model
  - (a) Allows Inputting Instrument Data as Available
  - (b) Expandable Number of Nodes as Required for Future Development
- * Power Requirements are Reasonable for Thermal Conditioning
- β-Cloth Not Adequate - Other External Coatings Required
- Low Cost/Low Risk Approaches Considered Throughout

Key issues associated with the use of graphite-epoxy for optical structures include the following areas, all potentially problem makers:

- Material Properties
- Dimensional Stability
- Hygroscopicity
- WeightLoss
- Outgassing
- Resistance to Microcracking

Detailed discussions have been held with General Dynamics, Convair Division - a major fabricator of graphite-epoxy structures - to address some of these questions. Review of the data contained therein indicates that the issues of concern are well understood and that viable, although proprietary, solutions exist to deal with these problems.

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* This consideration has been explored more fully in the Electronics/Command and Data Handling System. These is not enough power available at the IPS gimbals to both power the instruments and provide thermal conditioning for the Facility and Instruments.

STARLAB TRACKING AND ACQUISITION STUDY

Ball Aerospace Systems Division July 1978

The primary objective of this study was to develop an IMC that could limit focal plane errors caused by Vernier thruster firings to less than .06 arc-sec (peak). At the same time, quiescent noise was to be kept below .02 arc-sec (RMS).

- An IMC which meets the first requirements has been developed.

To achieve the necessary transient attenuation, a relatively wide bandwidth servo was required. The IMC error sensors include Fine Guidance Sensor (FGS) in the focal plane, a gyro, and a secondary mirror encoder to extend the error signal bandwidth. However, by extending the IMC bandwidth and including the additional sensors, the system becomes noisier. The system which meets the transient response requirements when subjected to a noise analysis exhibited a quiescent noise level of 0.171 arc-sec. This was due mostly to gyro noise although FGS noise(.03 arc-sec) alone exceeds the .02 arc-sec requirement. Since the Starlab optics correct the image to 0.2 arc-sec over the data field, this background noise level is enough to begin to degrade the image. Because of these results, Ball investigated the case where the IMC was designed to meet the quiescent noise requirement with a man-motion disturbance replacing the thruster firing. For this analysis, the FGS was the only error sensor. The results are:

- Noise = .015 arc-sec RMS
- Transient = .057 arc-sec RMS

The IMC proposed in this study cannot compensate for roll disturbance. The IPS specification for roll stability are (adequate) to meet the STARLAB requirements.

Shuttle/Spacelab procedural requirements during observations should reduce the man-motion impulses and the use of the shuttle free-drift mode is to be explored.

Also presented in detail are the following:

- Target Acquisition Sequence
- Focus Control of the Telescope
- Kalman Filtering in the IMC

ELECTRONICS/COMMAND AND DATA HANDLING SUBSYSTEM
Ball Aerospace Systems Division July 1978

The results of this study indicate that command and data handling (C&DH) system described in the report in conjunction with the capabilities of Shuttle/Spacelab systems, will meet very nearly all of the requirements established for Starlab. For all but one item, the exceptions identified will have no significant impact on Starlab objectives. The singular problem: lack of sufficient power to both maintain an active thermal control and provide for C&DH and instruments. Further study of all aspects of the power situation is recommended.

The C&DH subsystem is comprised of the following major components:

- Telescope processor
- Digital multiplexer
- Analog multiplexer
- A/D converter
- CCTV video selector switch
- Science data multiplexer

All commands, telemetry, and DEP links are accomodated by three Remote Acquisition Units (RAU) Spacelab interfaces. The science data will be transmitted via the High Rate Multiplexer (HRM).

Other, less urgent, candidates for continued investigation include:

- Investigation of ground data management plans to determine impact on Starlab science data requirements.
- Establish facility with which Starlab may be operated from the DDU (to the Keystroke level).
- Determine methods of adding FGS target information to the acquisition camera CCTV display.

Contamination Considerations

Contamination control of the STARLAB Telescope optical system has remained an area of great concern to the FDT from the initial facility concept through the present subsystem design study phase. There does exist a great wealth of knowledge as a result of effort that has been expended by the Aerospace Industry in the area of general contamination evaluation, that permits qualification of assembly work areas in which a system is brought from the subassembly level to the final package configuration. With STARLAB, contamination control must extend through these assembly phases and include the initial deployment and operation of the facility, the recovery, storage and reuse.

The Starlab telescope, as intended to be used in the near and far UV, cannot be an unprotected system onboard Shuttle. It must be provided with a seal and purge protective system of dry N_2 or the like. This will provide protection from both the scatter degrading properties of particulate contamination and UV absorbing and mirror coating destructive hydrocarbon deposits.

Contamination from the shuttle vernier thrusters is an important consideration when attitude holding and maneuvering is considered. Contamination from other sources (such as outgassing of Shuttle and the payload bay and water dumps) are also of critical concern to STARLAB. Such contamination has three undesirable effects for astronomical telescopes:

- Thin films of contamination deposited on mirror surfaces may drastically reduce reflectivity in both the ultraviolet and the infrared regions of the spectrum
- Column densities of molecules surrounding the spacecraft may be sufficiently high to impress molecular absorption features on the spectra of the cosmic sources being observed
- Very tenuous clouds of molecules or solid particles will add substantially to the background sky brightness of the day side of the orbit, and will critically affect the ability to observe faint objects for at least 60% of the orbital observing time.

The Structural/Thermal Design Study did present a conceptual operational contamination control plan, however, the Facility Systems Definition Design Study was to have extended these concepts for contamination definition and control for the STARLAB facility. The contamination factor remains a critical element to the successful operation of the telescope.

Stability

Image Motion Compensation

The Perkin-Elmer report quotes a required pointing stability of .01 arcsec rms to .03 arcsec rms. The value of ± 0.03 arcsec seems reasonable since the spot size (60% encircled energy) is 0.3 arcsec. Note that compensation will be performed by articulation of the secondary mirror. Since the magnification is 7.5, this implies that the secondary mirror must be articulated with a precision of ± 0.03 arcsec/7.5 = $\pm$0.004 arcsec, or 2×10^{-8} radians. Since the secondary mirror diameter is 200 mm, the alignment of opposite edges must be controlled to a 1σ precision of 2×10^{-8} rad x 0.2 m = 40Å.

Note that this is a value for precision and not for absolute accuracy. The alignment tolerances are much less critical:

- ± 0.5 mm lateral and ± 0.1 mm radial.

Stability is required over an integration time of up to ten hours.

Facility Mechanical Design Tradeoffs

Several conclusions about the baseline design can be made.

The first and most important conclusion is that as currently configured the baseline design is adequate to meet all design requirements (stiffness, deflection, weight, packaging, interfaces, etc.).

The second conclusion is that while margins exist for some of the design parameters of the system (i.e., stress, weight), the system is not overdesigned. It is felt that the level of the margins is consistent with the level of development of the design. As the design matures and more development occurs, weights and stresses tend to rise.

The third conclusion is that the design has been configured to maximize the use of cost-effective, proven designs. This will ensure minimization of risks, less need for new development, and maximization of reliability. However, it should be emphasized that to achieve the low cost designs, weight (consistent with system weight budgets) has been sacrificed. If weight becomes a future issue, the design can be easily lightened by the substitution of materials and/or configurations.

VII. TECHNICAL RECOMMENDATIONS

The subsystem studies for Phase B have resulted in the conclusions as presented in the preceeding section of this document. Generally it is developed, that as a result of a study, supplementary topics surface or additional design and study need be devoted to a particular area. The recommendations include areas that were intended to be incorporated in the Facility Systems Definition study.

1.0 FOCUS

In order to have reasonable tolerances for thermal gradients, thermal excursions, and variations in thermal expansion coefficients for the primary mirror it is necessary to employ a focus control. Current recommendations from Perkin-Elmer are for alignment to be fixed on the ground, but for focus to be adjustable on-orbit. The focus control study should be extended to include the tradeoffs between tight active thermal control of the telescope metering structure and a focus implementation which can compensate for thermal excursions and gradients. Every effort must be expended to reduce the power requirements for the present active thermal control loop which when coupled with the other subsystems, exceeds the available input. The increased use of thermal insulation and athermal focal control might be explored.

2.0 FOCAL PLANE STRUCTURE

Two candidate arrangements were considered in the Instruments Concept Study. The first assumes the additional radial instruments to be placed at 90° to the principal radial instrument, the second at 120°. A significant difference between the two arrangements is that more space is available between the instrument selector and the instruments in the orthogonal than in the equilateral case. This is important with regard to accomodation of filterwheels, and other auxiliary equipment and is, therefore, the arrangement recommended. However, in The Perkin-Elmer Structural/Thermal Subsystem Design study, a hexagonal truss structure is assumed to connect the main ring to the IPS. This has the advantage of a three-point attachment, but forces the radial instruments, which protrude through the truss structure, to be arranged in the equilateral pattern. For the sake of consistency between the studies, BASD focused their attention mainly on the equilateral arrangement, but recommend that the orthogonal version be seriously reconsidered in the Phase-B Facility Systems Definition study.

A square or octagonal IPS connecting structure would then be needed. Structures of this type are quite common in modern ground-based telescopes and might, in fact, even be preferred for STARLAB if a compliant IPS connecting structure is found desirable, as was investigated in the Acquisition and Tracking Subsystem study at BASD.

As presently configured, the radial instrument tends to be short and squat. For further consideration a Science Instrument is envisioned that would occupy the length of the Aft Instrument enclosure and would receive its optical input via the radial instrument mount and selector.

3.0 STRUCTURAL DESIGN

The final conclusion in the Thermal Structural Subsystem Design directs itself toward future structural studies. It states that the baseline design presented is by no means fully optimized or studied. The next step toward this end would involve investigation of those items not addressed in this study, such as interface (joint), design, detailed study of smaller components and subsystems, closer investigation of the fabrication aspects of the designs, in-depth analyses of the structure including structural/thermal modeling, and, finally, considerations of integration and test.

4.0 THERMAL DESIGN

Although more sophisticated than those reported earlier in the Phase A study report, the Thermal Control System (TCS) design results of the Thermal/Structural study should be considered preliminary. The axial and radial instruments, for example, are represented by only one node each in the thermal model. As the model becomes more complex in future studies, the results will become more precise and hence should be more reliable. Nevertheless, the following TCS improvements are believed necessary at this time:

- The TCS for controlling alignment of the Science Instrument should be more positive. Small property variations, minor system failures, component degradation, etc., can easily cause the TCS to lose temperature control.
- The power requirements for thermal conditioning should be reduced, analytically, early in the design phase since they tend to increase as the design progresses.
- The evaluation of control of thermal uniformity and stabilization times on the metering structure should be expanded. The use of thermal blankets and athermal struts would be considered.

5.0 POINTING SYSTEM

The results of Acquisition and Tracking study show that quiescent disturbance level is a more difficult requirement to meet than attenuation of discrete transient disturbances. For this reason, the Starlab pointing subsystem definition should continue with emphasis on the following areas:

- Review and redefinition of focal plane stability requirements. This would include the basic corrected resolution capability of the optics and the combination of the two principal inputs at quiescent conditions: IPS torque noise level and IMC noise level.

- Design of a bandwidth-limited IMC system that is designed to meet the IMC quiescent noise level. Determination would then be be made of the performance of this IMC system in the presence of discrete inputs.
- Assessment of the operational limitations, if any, imposed by the total system response to discrete inputs. This might involve rejection of data taken during long thruster firings, limitations of crew motions, or use of Orbiter free-drift modes. The effect of occasional discrete transient motions on data quality would also be assessed. This would include the effect on both imaging and spectral types of focal plane instrumentation.

5.1 Kalman Filter

It has been shown that the singular problem encountered in implementing a Kalman filter for the IMC is the tremendous computational load imposed on the computer. Several techniques might be used to alleviate these difficulties. These techniques fall into two categories; first, make the computer more efficient and, second, reduce the computing requirements.

6.0 FACILITY PRIME POWER

Since there is a considerable disparity between available and required power, further investigation is required in this area. Determination of the optimum way to manage aft bay power for the instruments involves additional structural and thermal design considerations fundamental to the Starlab telescope facility operation. Several areas, however, in which efforts to improve the power problem will yield the most results are:

- Increase power available at gimbals.
- Reduce or eliminate forward bay heater power
- Investigate alternate implementations of the IMC control law to reduce power
- Refine and reduce instrument power requirements
- Increase power supply efficiency.

VIII. REFERENCES

1. "Optical Subsystem Design," Final Technical Report, March 1978, Perkin-Elmer Report No. 13726

2. "Structural/Thermal Subsystems Definition Design Study," Final Report, March 1978, Perkin-Elmer Report No. 13712

3. "Instrument Concept Design Study," Final Report, April 1978, Ball Aerospace Systems Division, Report No. F78-05

4. "Acquisition & Tracking Subsystem Definition Design Study," Final Report, May 1978, Ball Aerospace Systems Division

5. "Electronics/Command & Data Handling Subsystem Definition Design Study," Interim Report, April 1978, Ball Aerospace Systems Division/ Western Aerospace Laboratory

6. "Report of the Facility Definition Team Spacelab UV-Optical Telescope Facility," December 1975, GSFC Facility Definition Team

7. "Telescope Optical Design Concepts Study in Support of the Facility Definition Team, Final Report;" October 1975; Ball Brothers Research Corporation under GSFC Contract NAS5-24048, Mod. 17

8. "Feasibility Study of the Spacelab Ultraviolet Optical Telescope Facility," October 1975, Ball Brothers Research Corporation under GSFC Contract NAS5-24048, Mod. 20

9. "Starlab Definition Support Study," August 1977, Ball Brothers Research Corporation, BBRC Report #F77-20

10. "Spacelab Payload Accommodations Handbook," NASA-ESA, 1976 -- Reprinted January 1977

11. "Preliminary Study of Spacelab Ultraviolet-Optical Facility Telescope", Final Report, November 1974, Ball Brothers Research Corporation under GSFC Contract NAS5-24048

12. "Feasibility Study to Use Existing Hardware for STARLAB," January 1977, Martin-Marietta Corporation

13. "STARSAT - A Space Astronomy Facility," July 1976, NASA TM X-73326, MSFC

14. "STARLAB Alternatives Study," Final Report, July 1977. Martin Marietta Corporation Report MCR-77-261, GSFC Contract NAS5-23428. Mods. Nos. 14 & 19

15. Specification, Instrument Pointing Subsystem, IPS-DS-SP-0001, Issue 1, Dornier System, December 23, 1976.

16. "Instrument Pointing Subsystem," Preliminary Design Review Data Package, November 1977, Dornier System Doc. No. 99 ICD-IPS

17. Instrument Pointing System Operations Implementation Plan, Preliminary, MSFC, February 1, 1978.

18. "Feasibility Study for the Use of the PDP-11/34M and LSI-11M Computers in the Spacelab Experiment Environment," Summary of Phase I Report, February 1978, Norden Systems Computer Products Center, GSFC Contract NAS5-24413

19. "Experiment Computer Operating System Requirements Definition Document," January 1978, McDonnell Douglas Corporation, MDC G6862A, NASA Contract NAS8-32350

20. "Spacelab Program Software User's Guide," January 1978, McDonnell Douglas Corporation, MDC G6854A, NASA Contract NAS8-32350

21. "Payload Specialist Station Study," November 1976, Martin Marietta Corporation, MCR-76-403, Volume 1 & 2, NASA Contract NAS8-31789

22. "Shuttle-Orbiter/Cargo Standard Interface," October 1977, NASA Johnson Space Center, ICD No. 2-19001

APPENDICES

It was deemed appropriate that this document be a convenient source of all available STARLAB Program information. To this extent the following information is included as appendices; in Volume 2.

- STARLAB Facility Systems Definition Design Statement of Work (SOW)
- Costing Information for all of the Phase B subsystem studies.